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AN ANALYTICAL MODEL OF KINETIC ENERGY PROJECTILE/FRAGMENT PENETRATION

John Zook

October 1977

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USA ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
USA BALLISTIC RESEARCH LABORATORY
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The basis for an analytic model of kinetic energy projectile (fragment) penetration is described. It is based on an expression for the resistive force encountered by a projectile during penetration. The predictive capability of the model is compared to that of the Thor equation for residual velocity. Some conclusions are drawn concerning the penetration process. A tabulation of computer programs, and sample output are included.

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I. INTRODUCTION

Numerous empirical equations (see Table I, of which the major portion is a compilation made by Herrman and Jones[1]. The geometric values listed in the table have been converted to the metric system (cgs) system of units) are available for predicting depth of penetration and residual velocities for various projectile-target combinations. (Projectile and fragment may be used interchangeably through this report.) Unfortunately, since the equations are empirical, each equation is applicable only in the region of the data used to generate the empirical constants. Any extrapolation outside the range of the data is questionable.

Extended use has been made at the BRL of the equations developed under the code name "Project Thor"[2]. The equation for residual velocity for perpendicular impact (0° obliquity) is:

$$V_r = V_s - 10^a\ (X_t A)^b m_p^c\ V_s^d\ . \tag{1}$$

The values for the empirical exponents a, b, c and d determined by a least squares fit to experimental data are tabulated in Table II for various target materials along with the range of plate thickness X_t, striking velocity V_s and the area A and mass m_p of the projectile. Since the Thor equation is so widely used at the BRL, in order for any model predicting residual velocity to qualify as a replacement to this equation, it should be more accurate in its prediction or should exhibit other qualities which render it more useful - for example, allow extrapolation with greater confidence than a purely empirical model.

It is desirable to develop a theoretical model which can be used in general to predict terminal ballistics. Needless to say, projectile-target interactions are complex. Although kinetic energy projectiles have been used for several centuries, no single predictive model has been found to be applicable for all test conditions.

The model to be discussed in this report is completely general in that its use does not require a data base to generate new empirical constants. The model is a modification of an analytic approach for predicting residual velocity of penetrators impacting targets at 0°

[1] *Herrman and Jones, "Correlation of Hypervelocity Impact Data," Proceedings of the Fifth Symposium on Hypervelocity Impact, Vol. 1, Part 2, April 1962.*

[2] *Project Thor, "The Resistance of Various Metallic Materials to Perforation By Steel Fragments; Empirical Relationships for Fragment Residual Velocity and Residual Weight," Technical Report #47, Ballistic Analysis Laboratory, Institute for Cooperative Research, The Johns Hopkins University, April 1961.*

TABLE I POSTULATED EMPIRICAL EQUATIONS

PENETRATION EQUATION	TARGET MATERIAL	PROJECTILE MATERIAL	PROJECTILE SHAPE	PROJECTILE SIZE	STRIKING VELOCITY	INVESTIGATOR	REF NR.
$X_t = \left[\frac{3K_1K_2}{2\pi}\right]\left[V_p \frac{\rho_p}{\rho_t}\right]^{1/3}\left(\frac{V}{\bar{C}_t}\right)\left[\frac{1}{3 - K_2\frac{V}{\bar{C}_t}}\right]$	ALUMINUM WAX (10°C) BRASS LEAD MAGNESIUM STEEL ZINC	ALUMINUM BRASS LEAD MAGNESIUM STEEL ZINC	SPHERE	0.318 CM DIA.	$\frac{V}{\bar{C}_t} \leq 1.0$	VAN VALKENBERG et. al.	1
$X_t = 2.5\ D \left[\frac{V}{\bar{C}_t}\right]^{1.4}$	ALUMINUM BRASS LEAD	ALUMINUM BRASS LEAD	SPHERE	0.318 CM DIA.	$0.1 \leq \frac{V}{\bar{C}} \leq 1.0$	HUTH et. al.	1
	MAGNESIUM MAGNESIUM-LITHIUM LEAD	MAGNESIUM MAGNESIUM-LITHIUM LEAD	CYLINDER				
$X_t = K \left(\frac{M_p V}{\rho_t}\right)^{1/3}\left(\frac{1}{H^{1/4}}\right)$	ALUMINUM BRASS BRONZE COPPER MALLORY STEEL TITANIUM	- - -	SHAPED CHARGE JET	- - -	3200 M/S	PUGH AND EICHELBERGER	1
	LEAD	STEEL	DISC	- - -	400 - 3200 M/S	KINEKE	1

TABLE I POSTULATED EMPIRICAL EQUATIONS (CONTINUED)

PENETRATION EQUATION	TARGET MATERIAL	PROJECTILE MATERIAL	PROJECTILE SHAPE	PROJECTILE SIZE	STRIKING VELOCITY	INVESTIGATOR	REF NR.
$X_t = \dfrac{V_p(1 - e^{-K_4 E})}{K_1 K_3 \sqrt{2M_p E} + K_2}$	LEAD	LEAD	SPHERE	0.318 CM DIA. 0.476 CM DIA. 0.952 CM DIA.	<1800 M/S	VAN FLEET et. al.	1
$X_t = K\, M_p^{1/3} \dfrac{(V - V_0)}{\bar{C}_t}$ FOR $\dfrac{V_0}{\bar{C}_t} < \dfrac{V}{\bar{C}_t} < 2$	WAX (23°C)	WAX (4°C)	SPHERE	0.450 CM DIA.	$0.3 < \dfrac{V}{\bar{C}_t} < 2.2$	PARTRIDGE AND CLAY	1
			CYLINDER	0.559 CM DIA. 0.838 CM LONG AND 0.985 CM LONG			
$X_t = D\left[\dfrac{K_1 \rho_p V}{(C_t \rho_t + C_p \rho_p)} - \dfrac{K_2 Y_t \rho_p^{1/2}}{C_t^2 \rho_t^{3/2}}\right]$ $1.5\,D \leq X_t \leq 5\,D$	ALUMINUM 1100 ALUMINUM 2024-0 COPPER LEAD STEEL	MERCURY	SPHERE	- - -	<2000 M/S	ENGEL	1
	ALUMINUM 2024-0 COPPER LEAD	WATER					
	ALUMINUM COPPER IRON ZINC LEAD	ALUMINUM COPPER IRON ZINC LEAD					

TABLE I POSTULATED EMPIRICAL EQUATIONS (CONTINUED)

PENETRATION EQUATION	TARGET MATERIAL	PROJECTILE MATERIAL	PROJECTILE SHAPE	PROJECTILE SIZE	STRIKING VELOCITY	INVESTIGATOR	REF NR.
$X_t = K\,D\left(\frac{V}{\bar{C}_p}\right)^{\bar{C}_t/\bar{C}_p}$	ALUMINUM COPPER LEAD STEEL TIN	ALUMINUM COPPER MALLORY 1000 STEEL	FRAGMENT	- - -	300 - 1800 M/S	McKENZIE et. al.	1
$X_t = 2.28\,D\left[\frac{V}{\bar{C}_t}\,\frac{\rho_p}{\rho_t}\right]^{2/3}$	COPPER LEAD	ALUMINUM COPPER LEAD MAGNESIUM-LITHIUM STEEL TUNGSTEN	SPHERE	0.452 CM DIA. 0.302 CM DIA. 0.277 CM DIA. 0.554 CM DIA. 0.318 CM DIA. (ALL MATERIALS) 0.244 CM DIA.	< 3400 M/S	CHARTERS AND LOCKE	1
	ALUMINUM MAGNESIUM NICKLE POLYETHELENE STAINLESS-STEEL	STAINLESS-STEEL	MICRO-PARTICLE	100 MICRONS AND 150 MICRONS	700 - 4000 M/S	ANDERSON	1
$X_t = \left[\frac{3\,M_p}{4\pi K\,H}\right]^{1/3} V^{2/3}$	ALUMINUM COPPER STEEL	- - -	- -	- - -	- - - -	N.R.L.	1

TABLE I POSTULATED EMPIRICAL EQUATIONS (CONTINUED)

PENETRATION EQUATION	TARGET MATERIAL	PROJECTILE MATERIAL	PROJECTILE SHAPE	PROJECTILE SIZE	STRIKING VELOCITY	INVESTIGATOR	REF NR.
$X_t = 1.9\, D\left(\frac{V}{\bar{C}_t}\right)\left(\frac{\rho_p}{\rho_t}\right)$	ALUMINUM STEEL STEEL	ALUMINUM (ALUMINUM, STEEL) MAGNESIUM (STEEL)	SPHERE	0.508 CM DIA. AND 1.016 CM DIA.	$\leqslant$ 5400 M/S	MAIDEN et. al.	1
$X_t = 2.8\, D\left(\frac{V}{\bar{C}_t}\right)^{0.7}\left(\frac{\rho_p}{\rho_t}\right)^{0.8}$	COPPER LEAD	ALUMINUM	SPHERE	0.508 CM DIA. AND 1.016 CM DIA.	$\leqslant$ 5400 M/S	MAIDEN et. al.	1
$X_t = 2\, D\left(\frac{V}{\bar{C}_t}\right)^{0.75}$	STEEL	STEEL	SPHERE	0.508 CM DIA.	$\leqslant$ 5400 M/S	MAIDEN et. al.	1
$X_t = \frac{K_1(\rho_p V L - K_2)}{\rho_p^{K_3}(E_t + K_4)^{K_5}}$	ALUMINUM COPPER LEAD STEEL	ALUMINUM COPPER LEAD STEEL	SPHERE CYLINDER (L/D=1)	0.157 CM DIA. 0.559 CM DIA. 1.270 CM DIA. 0.559 CM DIA. 1.270 CM DIA.	$\leqslant$ 4000 M/S	COLLINS AND KINARD	1
$X_t = \frac{K}{2} M^{1/3} V^{2/3}$	CADMIUM COPPER LEAD ZINC	- - -	- - -	- - -	- - -	B.R.L.	1

TABLE I POSTULATED EMPIRICAL EQUATIONS (CONTINUED)

PENETRATION EQUATION	TARGET MATERIAL	PROJECTILE MATERIAL	PROJECTILE SHAPE	PROJECTILE SIZE	STRIKING VELOCITY	INVESTIGATOR	REF NR.
$X_t = K_1 D \left(\frac{\rho_p}{\rho_t}\right)^{2/3} \ln\left[1 + \frac{\left(\frac{\rho_p}{\rho_t}\right)^{2/3}\left(\frac{\rho_t V^2}{H_t}\right)^{1/3}}{K_2}\right]$ $K_1 \approx 0.6 \quad K_2 \approx 4 \qquad D = \left(\frac{6M}{\pi \rho_p}\right)^{1/3}$	EMPIRICAL FIT TO 1700 DATUM SETS GENERATED AT FIFTEEN LABORATORIES COMPRISING 52 PROJECTILE MATERIAL/ TARGET MATERIAL COMBINATIONS.				500 - 3600 M/S	HERRMAN AND JONES	1
$V_r = V_s - 10^E (X_t A_p)^F M_p^G V_s^H$ $X_t = \left(\frac{1}{A_p}\right)\left[\frac{V_s - V_r}{10^E M_p^G V_s^H}\right]^{1/F}$ E, F, G AND H ARE EMPIRICAL CONSTANTS	MAGNESIUM	STEEL (SAE 1020)	CYLINDER AND CUBE-ON-CYLINDER (L/D≈1)	0.592 CM DIA. TO 1.745 CM DIA.	690 - 3200 M/S	PROJECT THOR	2
	ALUMINUM				340 - 1800 M/S		
	TITANIUM				550 - 2600 M/S		
	CAST IRON				570 - 1800 M/S		
	STEEL (ROLLED HOMOGENEOUS AND FACE-HARDENED)				300 - 1660 M/S 750 - 3000 M/S		
	COPPER				350 - 3300 M/S		
	LEAD				700 - 2600 M/S		
	TUBALLOY				500 - 2800 M/S		
$X_t = \left[\frac{M_p V_s^2}{K D^{(3-N)}}\right]^{1/N}$	- - -	- - -	- - -	- - -		De MARRE	5

[5] Ogorkiewicz, R. M., *"Design and Development of Fighting Vehicles,"* Doubleday & Company, Inc., 1968.

Table II. The Thor Equation

$$V_r = V_s - 10^a \,(XA)^b M_s^c \, V_s^d \quad \text{or} \quad X = \frac{1}{A}\left[\frac{V_s - V_r}{10^a M_s^c \, V_s^d}\right]^{1/b}$$

where: V_r - residual velocity (cm/sec) , X - plate thickness (cm) ,
V_s - striking velocity (cm/sec) , M_s - striking mass (grams) ,
A - projectile cross-sectional area (cm^2) ,
a, b, c and d are tabulated below.

	Empirical Constant Exponents				Applicable Range			
	a	b	c	d	X (cm)	V_s (m/s)	M_s (gms)	A (cm^2)
Magnesium Alloy	5.801	1.092	-1.170	-0.087	0.30-7.62	690-3200	2-16	0.45-1.75
Aluminum Alloy	6.214	1.029	-1.072	-0.139	0.30-2.54	340-1800	2-16	0.45-1.75
Titanium Alloy	4.888	1.103	-1.095	0.167	0.10-1.30	550-2600	2-8	0.45-1.26
Cast Iron	5.034	1.042	-1.051	0.523	0.45-1.50	570-1800	1-16	0.28-1.75
Rolled Steel (RHA)	5.690	0.889	-0.945	0.019	0.05-1.27	300-1660	2-16	0.45-1.75
Face Hardened Steel	3.438	0.674	-0.791	0.434	0.30-1.27	750-3000	1-16	0.28-1.75
Copper	1.388	0.678	-0.730	0.802	0.15-2.54	350-3300	1-16	0.28-1.75
Lead	1.067	0.499	-0.502	0.818	0.30-2.54	700-2600	2-16	0.45-1.75
Tuballoy	1.368	0.583	-0.603	0.828	0.25-0.51	500-2800	2-30	0.45-2.39

obliquity proposed by Otto P. Fuchs.[3] The remainder of this report is a discussion of his model, the modification that has been made, and supportive arguments for use of the model.

II. THE RESISTIVE FORCE

The expression for the resistive force acting during the penetration process as proposed by Fuchs involves a sum of three components that are functions of the instantaneous velocity:

$$F = f_1 (V^0) + f_2 (V^1) + f_3 (V^2). \tag{2}$$

The first component, a static force, is defined as the product of the projectile cross-sectional area and a stress factor. The stress factor is closely approximated by the target Brinell hardness when expressed in dynes/cm^2. (The Brinell hardness number is multiplied by 9.8×10^7 to obtain the value in dynes/cm^2). The first component is:

$$f_1 (V^0) = A H_t. \tag{2a}$$

The second component is a combination of the first and third components, hence, the third component will be presented next. Analogous to the aerodynamic resistive force, the third component is:

$$f_3 (V^2) = C A \rho_t V_x^2. \tag{2b}$$

Returning now to the second component, it is defined to be:

$$\begin{aligned} f_2 (V^1) &= 2 \sqrt{f_1 (V^0) \, f_3 (V^2)} \\ &= 2A \sqrt{C H_t \rho_t V_x^2}. \end{aligned} \tag{2c}$$

This component can be compared to Stoke's Equation[4] in which the resistive force is proportional to the velocity.

A more general form for the resistive force equation has been adopted since the equation proposed by Fuchs did not yield satisfactory results when applied to available data. The generalized equation is:

---

[3] *Fuchs, Otto P., "Impact Phenomena," AIAA Journal, American Institute of Aeronautics and Astronautics, Vol. 1, Nr. 9, Sept. 1963.*

[4] *Ference, M., Lemon, H., and Stephenson, R., "Analytical Experimental Physics," University of Chicago Press, 1956.*

$$F = A\ (C_1\ H_t + C_2\ \sqrt{H_t\ \rho_t}\ V_x + C_3\ \rho_t\ V_x^{\ 2}). \qquad (3)$$

The coefficients C_1, C_2 and C_3 will be determined in Section V. Equation (3) can be expressed more succinctly as:

$$F = A\ (K_1 + K_2\ V_x + K_3\ V_x^{\ 2}). \qquad (3a)$$

III. THE DEPTH OF PENETRATION EQUATION

Newton's second law of motion states:

$$F = \frac{d(mV)}{dt} = m\frac{dV}{dt} = ma \qquad (4)$$

assuming that the mass is held constant. The work done in penetrating an increment "dx" is given by:

$$\text{Work} = F\ dx = -\ m\ dx\ \frac{dV}{dt} = -\ m\ \frac{dx}{dt}\ dV = -\ m\ V\ dV \qquad (5)$$

where the minus sign is due to deceleration.

Substitution of Equation 3a for the force and arranging terms yields:

$$dx = \frac{-\ m_p}{A}\left[\frac{VdV}{K_1 + K_2\ V + K_3\ V^2}\right]. \qquad (6)$$

For a specified striking velocity and residual velocity, Equation 6 is integrated to find the target plate thickness (or the maximum depth of penetration for zero residual velocity).

$$\int_0^{x_t} dx = \frac{-\ m_p}{A}\int_{V_s}^{V_r}\frac{VdV}{K_1 + K_2\ V + K_3\ V^2}. \qquad (7)$$

The projectile mass and cross-sectional area are assumed to be constant in Equation 7. In most cases, there is very little, if any, mass loss when penetrating a single target plate. When deformation of the projectile occurs, the cross-sectional area increases and should be accounted for. The effect of the cross-sectional area will be covered

in Section VII and will be assumed constant in performing the integration of the equation.

In order to integrate Equation 7, it is necessary to determine the value of the discriminant q, where $q = 4\,K_1\,K_3 - K_2^2$.

If $q > 0$, then:

$$X\Big|_0^{X_t} = -\frac{m_p}{A}\left(\frac{1}{2K_3}\right)\left[\ln\,(K_1 + K_2V + K_3V^2) - \frac{2K_2}{q^{1/2}}\left(\tan^{-1}\left(\frac{2K_3V + K_2}{q^{1/2}}\right)\right)\right]\Bigg|_{V_s}^{V_r}. \quad (8)$$

Substituting the limits and taking into account the negative sign yields:

$$X_t = \frac{m_p}{A}\left(\frac{1}{2K_3}\right)\left[\ln\left(\frac{K_1 + K_2V_s + K_3V_s^{\,2}}{K_1 + K_2V_r + K_3V_r}\right)\right. \quad (8a)$$

$$\left. + \frac{2K_2}{q^{1/2}}\left\{\tan^{-1}\left(\frac{2K_3V_r + K_2}{q^{1/2}}\right) - \tan^{-1}\left(\frac{2K_3V_s + K_2}{q^{1/2}}\right)\right\}\right].$$

When $q = 0$ (which is the condition for Fuchs' original equation), integration of Equation 7 yields:

$$X\Big|_0^{X_t} = -\frac{m_p}{A}\left(\frac{1}{K_3}\right)\left[\ln\left(K_1^{1/2} + K_3^{1/2}\,V\right) + \frac{K_1^{1/2}}{K_1^{1/2} + K_3^{1/2}\,V}\right]\Bigg|_{V_s}^{V_r}. \quad (9)$$

After substitution of the limits, Equation 9 becomes:

$$X_t = \frac{m_p}{A}\left(\frac{1}{K_3}\right)\left\{\ln\left(\frac{K_1^{1/2} + K_3^{1/2}\,V_s}{K_1^{1/2} + K_3^{1/2}\,V_r}\right) + \left[\frac{K_1^{1/2}}{K_1^{1/2} + K_3^{1/2}\,V_s}\right] - \left[\frac{K_1^{1/2}}{K_1^{1/2} + K_3^{1/2}\,V_r}\right]\right\}. \quad (9a)$$

Finally, if $q < 0$, Equation 7 is evaluated as:

$$X\Big|_0^{X_t} = \frac{-m_p}{A}\left(\frac{1}{2K_3}\right)\left[\ln\left(K_1 + K_2V + K_3V^2\right) - \left(\frac{K_2}{\sqrt{-q}}\right)\ln\left(\frac{2K_3V + K_2 - \sqrt{-q}}{2K_3V + K_2 + \sqrt{-q}}\right)\right]\Bigg|_{V_s}^{V_r} , \tag{10}$$

which is

$$X_t = \frac{m_p}{A}\left(\frac{1}{2K_3}\right)\left[\ln\left(\frac{K_1 + K_2V_s + K_3V_s^2}{K_1 + K_2V_r + K_3V_r^2}\right)\right.$$

$$\left. + \left(\frac{K_2}{\sqrt{-q}}\right)\ln\left(\frac{(2K_3V_r + K_2 - \sqrt{-q})(2K_3V_s + K_2 + \sqrt{-q})}{(2K_3V_r + K_2 + \sqrt{-q})(2K_3V_s + K_2 - \sqrt{-q})}\right)\right] . \tag{10a}$$

IV. THE TIME-PENETRATION EQUATION

The time to penetrate a target plate to a depth x can be found by again considering Newton's second law of motion.

$$F = - m \frac{dv}{dt} . \tag{11}$$

Substituting Equation 3a for the force, solving for the time, and integrating (assuming that the projectile mass and cross-sectional area are constant) yields:

$$\int_0^{T_x} dt = - \frac{m_p}{A}\int_{V_s}^{V_r} \frac{dV}{K_1 + K_2V + K_3V^2} , \tag{12}$$

(the minus sign is due to deceleration).

Again letting $q = 4K_1K_3 - K_2^2$, three cases exist:

For $q > 0$:

$$T_x = \frac{m_p}{A}\left(\frac{2}{q^{1/2}}\right)\left[\tan^{-1}\left(\frac{2K_3V_s + K_2}{q^{1/2}}\right) - \tan^{-1}\left(\frac{2K_3V_r + K_2}{q^{1/2}}\right)\right]; \quad (13)$$

For $q = 0$:

$$T_x = \frac{m_p}{A}\left(\frac{1}{K_3^{1/2}}\right)\left[\frac{1}{K_1^{1/2} + K_3^{1/2}\ V_r} - \frac{1}{K_1^{1/2} + K_3^{1/2}\ V_s}\right]; \quad (14)$$

For $q < 0$:

$$T_x = \frac{m_p}{A}\left(\frac{1}{\sqrt{-q}}\right)\ \ln\left(\frac{(2K_3V_s + K_2 - \sqrt{-q})\ (2K_3V_r + K_2 + \sqrt{-q})}{(2K_3V_s + K_2 + \sqrt{-q})\ (2K_3V_r + K_2 - \sqrt{-q})}\right); \quad (15)$$

where T_x is the time (in seconds) required for the fragment to penetrate to a depth x (or, in other words, until the velocity drops to the value V_r).

V. DETERMINATION OF THE CONSTANTS C_1, C_2 AND C_3

A non-linear least squares computer program was used to evaluate the constants C_1, C_2 and C_3. The experimental data are used in Equations 8a, 9a or 10a (depending on the value of the discriminant, q) to determine the best values for C_1, C_2 and C_3. To use the program, an initial guess is made for the values of the constants. The program computes new values for the constants based on values it computes for the partial derivatives of the plate thickness (the dependent variable) with respect to the constants. The statements to evaluate the partial derivatives are provided to the program in a subroutine and are tabulated in this report in Table IIIa. The computer program arrives at a convergent set of constants when the change in the value of each constant from one trial to the next becomes less than some predetermined tolerance value (0.01 was used in this case).

Listed in Table IIIb is a summary of the computational runs made. Shown are the initial guess values for the constants with the corresponding root-mean square error, then the general set of constants obtained when combining the data for all target materials, and finally, the convergent set of constants obtained for each target material. Also shown are the corresponding sigma and T-statistic test value for each constant of the convergent set. The data used are those tabulated in Appendix A with the exception of 20 out of the 277 datum sets.

Table IIIa. Statements To Evaluate Partial Derivatives For Non-Linear Least Squares Program

```
C     C
C     C           A = PROJECTILE CROSS-SECTIONAL AREA  (CM**2)
C     C          C1 = EMPIRICAL CONSTANT TO BE EVALUATED
C     C          C2 = EMPIRICAL CONSTANT TO BE EVALUATED
C     C          C3 = EMPIRICAL CONSTANT TO BE EVALUATED
C     C          HT = HARDNESS OF TARGET PLATE  (DYNES/CM**2)
C     C          MP = MASS OF PROJECTILE  (GRAMS)
C     C          P1 = FIRST DERIVATIVE OF XT WITH RESPECT TO C1
C     C          P2 = FIRST DERIVATIVE OF XT WITH RESPECT TO C2
C     C          P3 = FIRST DERIVATIVE OF XT WITH RESPECT TO C3
C     C        RHOT = DENSITY OF TARGET PLATE  (GRAMS/CC)
C     C          VR = RESIDUAL VELOCITY OF PROJECTILE  (CM/SEC)
C     C          VS = STRIKING VELOCITY OF PROJECTILE  (CM/SEC)
C     C          XT = TARGET PLATE THICKNESS  (CM)
C     C
C     C
      S=SQRT(RHOT*HT)
      B=S*VS
      C=RHOT*VS**2
      D=S*VR
      E=RHOT*VR**2
      F=2.0*S
      G=4.0*RHOT*HT
      H=S**2
      R=2.0*RHOT*VR
      T=MP/(2.0*A*RHOT)
      U=2.0*RHOT*VS
      Q0=(4.0*C1*C3-C2**2)*RHOT*HT
C     C
      IF(Q0.EQ.0.)GOTO 200
C     C
      IF(Q0.LT.0.)GOTO 300
C     C
C     C
C     C       THE DISCRIMINANT Q IS GREATER THAN ZERO
C     C
  100 Q1=C1*HT+C2*B+C3*C
      Q2=C1*HT+C2*D+C3*E
      Q3=SQRT(Q0)
      Q4=Q3**3
      Q5=C3*R+C2*S
      Q6=C3*U+C2*S
      Q7=ATAN(Q5/Q3)
      Q8=ATAN(Q6/Q3)
      Q9=F/Q3
      Q10=C2/Q3
      Q11=C3*F*G/Q4
```

Table IIIa. (Cont'd) Statements To Evaluate Partial Derivatives For Non-Linear Least Squares Program

```
      Q12=1.0+(Q5/Q3)**2
      Q13=1.0+(Q6/Q3)**2
      Q14=Q5/Q4
      Q15=Q6/Q4
      T1=C2*Q11*(Q8-Q7)/2.0
      T2=Q10*Q11*(Q6/Q13-Q5/Q12)/2.0
C     C
      P1=Q9*(HT/Q1-HT/C2+T1+T2)
C     C
      T3=(F/Q3+C2**2*F*H/Q4)*(Q7-Q8)
      T4=(S/Q3+C2*H*Q14)/Q12
      T5=(S/Q3+C2*H*Q15)/Q13
C     C
      P2=Q9*(B/Q1-D/Q2+T3+Q10*F*(T4-T5))
C     C
      T6=ALOG(Q2/Q1)/C3
      T7=C2*F*(C1*G/(2.0*Q4)+1.0/(Q3*C3))*(Q8-Q7)
      T8=(R/Q3-C1*G*Q14/2.0)/Q12
      T9=(U/Q3-C1*G*Q15/2.0)/Q13
C     C
      P3=Q9*(C/Q1-E/Q2+T6+T7+Q10*F*(T8-T9))
C     C
      XT=Q9*(ALOG(Q1/Q2)+C2*F/Q3*(Q7-Q8))
      RETURN
C     C
C     C
C     C         THE DISCRIMINANT Q IS EQUAL TO ZERO
C     C
  200 Q3=SQRT(C1*HT)
      Q1=Q3+SQRT(C3*RHOT)*VS
      Q2=Q3+SQRT(C3*RHOT)*VR
      Q4=0.5*SQRT(HT/C1)
      Q5=0.5*SQRT(RHOT/C3)*VS
      Q6=0.5*SQRT(RHOT/C3)*VR
      Q7=2.0*T/C3
C     C
      P1=Q7*Q4*(2.0/Q1-2.0/Q2+Q3/Q2**2-Q3/Q1**2)
C     C
      Q8=C2*SQRT(HT/C3)
      Q9=C2*Q8/2
      Q10=Q1-Q3
      Q11=Q2-Q3
      Q12=Q9+Q10
      Q13=Q9+Q11
C     C
      P2=Q7*Q8*(2.0/Q12-2.0/Q13+Q9*(1.0/Q13**2-1.0/Q12**2))
C     C
```

Table IIIa. (Cont'd) Statements To Evaluate Partial Derivatives For Non-Linear Least Squares Program

```
      T1=Q3/Q1-Q6/Q2
      T2=Q6/Q2**2-Q5/Q1**2
C     C
      P3=Q7*(Q3/Q1-Q3/Q2-ALOG(Q1/Q2)/C3+T1+Q3*T2)
C     C
      XT=Q7*(ALOG(Q1/Q2)+Q3/Q1-Q3/Q2)
      RETURN
C     C     THE DISCRIMINANT Q IS LESS THAN ZERO
C     C
  300 Q7=SQRT(-Q0)
      Q1= 1*HT+C2*B+C3*C
      Q2= 1*HT+C2*D+C3*E
      Q3=2.0*C3*R+C2*S-Q7
      Q4=Q3+2.0*Q7
      Q5=2.0*C3*U+C2*S+Q7
      Q6=Q5-2.0*Q7
      Q8=C2*S/Q7
      Q9=T/C3
      Q10=ALOG(Q3*Q5/(Q4*Q6))
      Q11=C3*G/(2.0*Q7)
      Q12=C2*H/Q7
      Q13=C1*G/(2.0*Q7)
      T1=C3*G*Q10/(-Q0)+Q11/Q3+Q11/Q4-Q11/Q5-Q11/Q6
C     C
      P1=Q9*(HT/Q1-HT/Q2+Q8*T1)
C     C
      T2=S/Q7-C2*H/(Q7**3)
      T3=(S-Q12)/Q3+(S+Q12)/Q5-(S+Q12)/Q4-(S-Q12)/Q6
C     C
      P2=Q9*(B/Q1-D/Q2+T2*Q10+Q8*T3)
C     C
      T4=Q8*Q10*(1.0/C3+C1*G/(2.0*ABS(Q0)))
      T5=(R+Q13)/Q3+(U-Q13)/Q5
      T6=(R-Q13)/Q4+(U+Q13)/Q6
C     C
      P3=Q9*(C/Q1-E/Q2-ALOG(Q1/Q2)/C3-T4+Q8*(T5-T6))
C     C
      XT=Q9*(ALOG(Q1/Q2)+Q8*Q10)
      RETURN
      END
```


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Table IIIb. Non-Linear Least Squares Fit to Thor Data

Target Material		Initial	General	Convergent	σ	T	Number of Datum Sets
Magnesium	C_1	0.40	0.70	1.96	1.72	1.1	22
	C_2	0.90	0.23	-1.17	1.84	-0.6	
	C_3	0.50	0.50	0.83	0.42	2.0	
	ERMS	0.72	0.60	0.58	-	-	
Aluminum	C_1	0.39	0.70	0.62	0.27	2.2	83
	C_2	0.68	0.23	0.41	0.52	0.8	
	C_3	0.41	0.50	0.40	0.21	1.9	
	ERMS	0.16	0.15	0.15	-	-	
Titanium	C_1	0.40	0.70	4.06	2.92	1.4	18
	C_2	0.80	0.23	-3.10	3.04	-1.0	
	C_3	0.50	0.50	1.38	0.74	1.8	
	ERMS	0.12	0.17	0.11	-	-	
Cast Iron	C_1	0.70	0.70	0.37	0.39	0.9	19
	C_2	0.23	0.23	0.13	0.58	0.2	
	C_3	0.50	0.50	0.53	0.18	0.3	
	ERMS	0.18	0.18	0.09	-	-	
Steel (RHA)	C_1	0.40	0.70	0.53	0.93	0.6	17
	C_2	0.40	0.23	0.31	1.32	0.2	
	C_3	0.30	0.50	0.34	0.44	0.8	
	ERMS	0.07	0.12	0.06	-	-	
Steel (FHA)	C_1	0.00	0.70	-3.4×10^{-4}	0.22	- .002	24
	C_2	0.20	0.23	1.18	0.30	3.9	
	C_3	0.50	0.50	0.33	0.10	3.4	
	ERMS	0.47	0.14	0.08	-	-	
Copper	C_1	0.10	0.70	0.48	0.98	0.5	27
	C_2	1.50	0.23	0.20	0.68	0.3	
	C_3	0.50	0.50	0.61	0.09	6.7	
	ERMS	0.16	0.18	0.09	-	-	

Table IIIb. (Cont'd) Non-Linear Least Squares Fit to Thor Data

Target Material		Initial	General	Convergent	σ	T	Number of Datum Sets
Lead	C_1	-1.00	0.70	-7.70	1.84	-4.2	26
	C_2	1.00	0.23	6.22	1.23	5.1	
	C_3	0.50	0.50	0.19	0.11	1.8	
	ERMS	0.36	0.34	0.30	-	-	
Tuballoy	C_1	-0.50	0.70	-0.34	0.59	-0.6	20
	C_2	1.00	0.23	2.08	0.81	2.6	
	C_3	0.25	0.50	0.30	0.22	1.4	
	ERMS	0.44	0.12	0.11	-	-	
Combined Data	C_1	0.40	0.70	0.70	0.12	5.7	257
	C_2	0.90	0.23	0.23	0.13	1.8	
	C_3	0.50	0.50	0.50	0.03	18.6	
	ERMS	0.29	0.23	0.23	-	-	

Table IIIc. Summary of Convergent Values For C_1, C_2 and C_3

Target	C_1	σ_1	C_2	σ_2	C_3	σ_3	Nr.	Final ERMS
Magnesium	1.96	1.73	-1.17	1.84	0.83	0.42	22	0.58
Aluminum	0.62	0.27	0.41	0.52	0.40	0.21	83	0.15
Titanium	4.06	2.92	-3.10	3.04	1.38	0.74	18	0.11
Cast Iron	0.37	0.39	0.13	0.58	0.53	0.18	19	0.09
Steel (RHA)	0.53	0.93	0.31	1.32	0.34	0.44	17	0.12
Steel (FHA)	-3.4×10^{-4}	0.22	1.18	0.30	0.33	0.10	24	0.08
Copper	0.48	0.98	0.20	0.68	0.61	0.09	27	0.09
Lead	-7.70	1.84	6.22	1.23	0.19	0.11	26	0.30
Tuballoy	-0.34	0.59	2.08	0.81	0.30	0.22	20	0.13
Combined Data	0.70	0.12	0.23	0.13	0.50	0.03	257	0.23

These 20 datum sets are tabulated in Table IV.

Two things should be noted concerning the values of Table IIIb. First, the values for the constants can vary considerably with little change in the root-mean square error. Secondly, the sigmas for the constants are large relative to the value of the constants for the individual target materials. This becomes more apparent in the summary Table IIIc. Therefore, the constants evaluated with the combined set of data seem to be relatively good estimates for a general set of constants. These values are: $C_1 = 0.70$, $C_2 = 0.23$ and $C_3 = 0.50$. (The values for Fuchs' original equation are 1.0, 1.414, and 0.50 when the shape factor is unity. However, Fuchs' equation corresponds to Equation 9a rather than 8a).

Substitution of the general set of constants into Equation 8a yields:

$$X_t = \frac{m_p}{A\,\rho_t}\left\{\ell n\left[\frac{0.7\,H_t + 0.23\sqrt{H_t\,\rho_t}\,V_s + 0.5\,\rho_t\,V_s^2}{0.7\,H_t + 0.23\sqrt{H_t\,\rho_t}\,V_r + 0.5\,\rho_t\,V_r^2}\right]\right.$$

$$+\ 0.396\left[\tan^{-1}\left(\frac{\rho_t\,V_r + 0.23\sqrt{H_t\,\rho_t}}{1.16\sqrt{H_t\,\rho_t}}\right)\right. \tag{16}$$

$$\left.\left.-\tan^{-1}\left(\frac{\rho_t\,V_s + 0.23\sqrt{H_t\,\rho_t}}{1.16\sqrt{H_t\,\rho_t}}\right)\right]\right\}.$$

The penetration time equation becomes:

$$T_x = \frac{2\,m_p}{1.16\,A\sqrt{H_t\,\rho_t}}\left[\tan^{-1}\left(\frac{\rho_t\,V_s + 0.23\sqrt{H_t\,\rho_t}}{1.16\sqrt{H_t\,\rho_t}}\right)\right.$$

$$\left.-\tan^{-1}\left(\frac{\rho_t\,V_r + 0.23\sqrt{H_t\,\rho_t}}{1.16\sqrt{H_t\,\rho_t}}\right)\right]. \tag{17}$$

Equation 8a along with the values for the constants C_1, C_2 and C_3 or in the form of Equation 16 will be referred to as the Z/F equation.

Table IV. Data Eliminated From Non-Linear Least Squares Fit to Thor Data

Target Material	Datum Set Nr.	H_t (Kg/mm^2)	X_t (cm)	M_p (gms)	D_p (cm)	V_s m/s	V_r m/s
Magnesium	21	72.0	2.540	15.56	1.49	1417.0	537.7
Aluminum	78	120.0	2.540	15.56	1.49	975.4	0.0
Titanium	1	190.0	0.127	1.95	0.76	567.8	521.2
	10	190.0	0.318	3.89	1.01	620.3	500.8
Steel (FHA)	2	400.0	0.345	1.95	0.76	748.3	0.0
	4	400.0	0.345	1.95	0.76	1081.7	0.0
	9	400.0	0.635	3.89	1.01	1066.8	0.0
	14	400.0	1.270	3.89	1.01	1791.0	0.0
Copper	18	42.0	0.318	7.78	1.27	745.5	501.7
Lead	1	5.5	0.318	1.95	0.76	2401.2	1066.8
	2	5.5	0.318	1.95	0.76	2439.9	914.4
	4	5.5	0.348	1.95	0.76	957.7	457.2
	6	5.5	0.348	1.95	0.76	1721.5	762.0
	11	5.5	0.698	3.89	1.01	757.7	533.4
	14	5.5	0.318	7.78	1.27	1810.5	1101.8
	25	5.5	0.635	15.56	1.49	2608.8	1005.8
	32	5.5	2.54	15.56	1.49	1263.7	762.0
Tuballoy	8	240.0	0.254	3.89	1.01	1471.6	823.0
	15	240.0	0.508	7.78	1.27	1699.9	1219.2
	22	240.0	0.508	30.16	1.74	2171.4	640.1

Total number is 20 sets.

VI. COMPUTING RESIDUAL VELOCITY

An iterative procedure must be adopted to solve Equation 16 for residual velocity. One procedure is to determine the force acting over consecutive Δx increments and compute the corresponding speed reduction. From Equation 5,

$$dv = -F\,dx/(m\,v) = -(K_1 + K_2 v + K_3 v^2)\,dx/(m\,v).$$

The algorithm displayed in Figure 1 outlines the procedure.

This model was chosen for computing the residual velocity because it allows flexibility in defining the force equation. There is no need to check the value of the discriminant q ($q = 4K_1K_3 - K_2^2$) since it does not appear explicitly in this approach. Admittedly, this model is an approximation to the integrated equation but little error is involved because of the imposed criterion of

$$\left| \frac{\Delta V' - \Delta V''}{1/2\ (\Delta V' + \Delta V'')} \right| < 0.001. \tag{18}$$

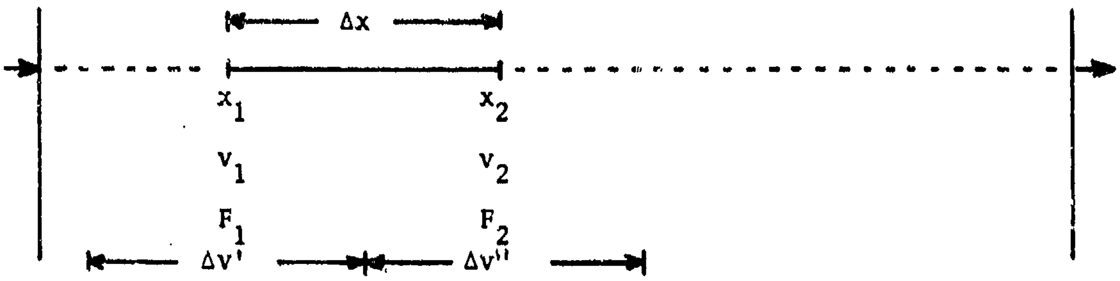
One problem that has been encountered occurs when the residual velocity approaches zero. The required Δx increment to cause the quantity of Equation 18 to be less than 0.001 becomes progressively smaller. Hence, a lower limiting value must be imposed on Δx or on the residual velocity in order to terminate the loop cycle. A tabulation of the computer program deck is given in Appendix C along with sample output.

An alternative method is to use Equation 16 by progressively increasing or decreasing the residual velocity value until the computed plate thickness yields the correct plate thickness to some degree of accuracy. A tabulation of such a program is included in Appendix C along with sample output of the program.

Also in Appendix C are tabulations of programs to find the plate thickness using Equation 8a and the Thor equation, and a program for finding residual velocity using the Thor equation. Sample output is included for each program.

VII. VALIDATING THE MODEL

One method for demonstrating the accuracy of a proposed model is to plot the predicted residual velocity or the predicted plate thickness against the experimental value. A perfect prediction will lie on the diagonal line. Plots are presented in Appendix B comparing the Thor equation with the Z/F equation for residual velocity and for plate thickness. The Thor data tabulated in Appendix A is used for making



1. Compute the force F_1 acting at depth x_1 based on velocity v_1:

$$F_1 = K_1 + K_2 v_1 + K_3 v_1^2 .$$

2. Compute the decrease in velocity $\Delta v'$ based on F_1; ($F\,dx = mv\,dv$):

$$\Delta v' = F_1 \, \Delta x / m_p \, v_1 .$$

3. Compute the force F_2 acting at depth x_2 based on the computed velocity at x_2, viz., $v_2 = v_1 - \Delta v'$:

$$F_2 = K_1 + K_2 v_2 + K_3 v_2^2 .$$

4. Compute the decrease in velocity $\Delta v''$ based on F_2:

$$\Delta v'' = F_2 \Delta x / m_p \, v_2 .$$

5. Test for $\left| (\Delta v' - \Delta v'') / \frac{1}{2} (\Delta v' + \Delta v'') \right| < 0.001$.

6. (a) Test condition satisfied.

   Set: $v_r = v_1 - (\Delta v' + \Delta v'')/2$,

   $F = (F_1 + F_2)/2$,

   $x = x_1 + \Delta x$,

   and repeat procedure until
   x = target plate thickness.

   (b) Fails test.

   Set: $\Delta x = \Delta x/2$

   Return to step 2.

Figure 1. Outline of Procedure to Find Residual Velocity

these comparisons. A study of the plots will show visually the accuracy and the similarity between the two models.

The Thor equation plots do not necessarily look like a least squares fit to the data because the exponents were obtained from a least squares fit to all the data for each target material reported in Reference 2. These data include oblique angle targets. What is plotted on the graphs of Appendix B is the data (tabulated in Appendix A) which involves normal impact only.

The similarity in the predictions made by the two equations and the poor showing for some of the data for each target material is likely due to inaccuracies in the data. The striking velocity and the residual velocity can be in error because of difficulties with the recording instrumentation. In some cases, the residual velocity was estimated from the depth of penetration into Celotex or similar material. Even in those cases where the residual velocity was determined from velocity screens and a chronograph, there can be doubt as to whether the same particle triggered both screens.

A second parameter which is possibly inaccurate is the cross-sectional area of the projectile on impact. The yaw angle was not reported, resulting in uncertainty concerning the orientation of the projectile. Table V lists the values for the cylindrical rod cross-sectional areas as a function of yaw angle. For example, the cross-sectional area for the 1.95 gram cylinder at 0° yaw is 0.452 cm^2. The maximum area occurs at about 40° yaw and is 0.611 cm^2. At 90° yaw (sideways impact) the cross-sectional area is the minimum - 0.411 cm^2. The uncertainty in the area can represent as much as a 26 percent error since the value which was used in both the Thor equation and the Z/F equation is the value at 0° yaw.

As indicated in Section III, the cross-sectional area was assumed to be constant when performing the integration. In reality, the projectile deforms and increases in cross-sectional area as it penetrates through the target plate. However, in using the non-linear least squares program to evaluate the three constants, the effect of the increase in projectile cross-sectional area was statistically taken into account. In other words, the particular values of the constants which were selected represent an average effect of the projectile penetrating the target plate.

The third parameter which is questionable is the target Brinell hardness. The values which were used are the nominal values reported in handbooks except an average value was used for cast iron and for the face-hardened steel Experience has shown that the actual Brinell hardness for a particular plate can vary by at least 20% from the handbook value and seems to be a function of plate thickness, at least in the case of 2024T-3 aluminum and rolled homogeneous steel.

Table V. Cross-sectional Areas By Yaw Angel For Cylinder Rods

Mass (gms) =	0.973	1.946	3.891	7.782	15.564	30.250
Radius (cms) =	0.296	0.380	0.506	0.633	0.746	0.872
Length (cms) =	0.457	0.541	0.617	0.795	1.143	1.661
Yaw Angle (degs.)			Areas (cm^2)			
0	0.275	0.452	0.804	1.259	1.748	2.389
5	0.298	0.487	0.856	1.342	1.890	2.632
10	0.318	0.517	0.901	1.414	2.018	2.856
15	0.336	0.543	0.939	1.476	2.130	3.057
20	0.351	0.566	0.969	1.527	2.226	3.236
25	0.364	0.584	0.993	1.566	2.305	3.389
30	0.374	0.597	1.009	1.593	2.367	3.517
35	0.381	0.606	1.017	1.608	2.410	3.618
40	0.385	0.611	1.018	1.611	2.435	3.692
45	0.386	0.610	1.010	1.608	2.442	3.737
50	0.384	0.605	0.995	1.580	2.430	3.755
55	0.379	0.596	0.973	1.546	2.400	3.743
60	0.372	0.582	0.943	1.501	2.351	3.703
65	0.362	0.563	0.906	1.444	2.284	3.635
70	0.348	0.541	0.862	1.376	2.200	3.539
75	0.333	0.544	0.811	1.298	2.100	3.416
80	0.314	0.483	0.755	1.210	1.983	3.267
85	0.294	0.448	0.692	1.112	1.851	3.094
90	0.271	0.411	0.624	1.006	1.705	2.897
Maximum Error =	+29%	+26%	+21%	+22%	+28%	+36%
	- 1%	-10%	-29%	-25%	- 3%	- 0%

$$\text{Area} = \Pi r^2 \cos \alpha + 2rL \sin \alpha$$

where: r - radius (cms),

L - length (cms),

and α - yaw angle (degrees).

Mathematical comparisons of the two equations are tabulated in Tables VIa, b, c and d. The definitions for the column headings are the following:

Number: number (n) of datum sets for the target material,

Mean: the arithmetic average $\overline{X} = \Sigma X_i/n$,

Variance: $(\Sigma(X_i^2) - n(\overline{X})^2)/(n - 1)$,

Standard Deviation: $= \sqrt{\text{Variance}}$,

D : the deviant (the difference between the predicted value and the experimental value),

R. E.: the relative error (the deviant divided by the experimental value),

and Σ : denotes summation.

Tables VIa and VIb are for plate thickness, and Tables VIc and VId are for residual velocity; the deviants and relative errors are presented respectively for both sets of tables. For some target materials, the Thor equation renders less error overall in its predicted values than the Z/F equation. For other target materials, the Z/F equation is better than the Thor equation. In all cases, the two equations do not yield grossly different results from each other.

The advantage of the Z/F equation is that it is more general in its application than the Thor equation. The Z/F equation may be used with some confidence for any case where the values of the parameters (target obliquity and Brinell hardness; projectile mass, cross-sectional area at impact, and striking velocity; and either plate thickness or projectile residual velocity) are known. By contrast, the Thor equation is limited to those projectile/target materials for which sufficient experimental data exists to evaluate the necessary empirical exponential constants. It is also limited to the range of values for each parameter for which data exists. As has been shown in Table II, the empirical constants vary from one target material to the next. The Thor equation is an expression involving parameters thought to be significant in the projectile-target interaction. On the other hand, the Z/F equation is based on an expression for the resistive force experienced by a projectile while penetrating a target. The three constants which appear in the equation were determined by fitting the depth-of-penetration equation to experimental data using a non-linear least squares procedure. While these constants have been evaluated empirically, the same values are used for all the target materials. As a result, one feels more confident in applying the Z/F equation to projectile/target materials in general.

Table VIa. Comparison of The Mean, Variance, Standard Deviation, Sum and Sum of Squares of The Plate Thickness Deviants

Target Material	Number	Mean	Variance	Standard Deviation	ΣD	ΣD^2	
Magnesium	23	0.129	0.753	0.868	2.966	16.952	Thor
	23	0.021	0.517	0.719	0.474	11.378	Z/F
Aluminum	84	-0.085	0.024	0.155	-7.127	2.606	Thor
	84	-0.066	0.016	0.129	-5.533	1.737	Z/F
Titanium	20	0.030	0.014	0.120	0.604	0.292	Thor
	20	0.033	0.024	0.155	0.665	0.480	Z/F
Cast Iron	19	0.015	0.010	0.102	0.284	0.190	Thor
	19	-0.144	0.006	0.077	-2.738	0.501	Z/F
Steel (RHA)	17	-0.094	0.002	0.048	-1.598	0.187	Thor
	17	-0.085	0.005	0.070	-1.442	0.201	Z/F
Steel (FHA)	29	0.012	0.015	0.124	0.363	0.436	Thor
	29	-0.090	0.014	0.119	-2.598	0.630	Z/F
Copper	28	0.022	0.011	0.107	0.627	0.324	Thor
	28	0.118	0.013	0.116	3.314	0.754	Z/F
Lead	34	0.180	0.337	0.581	6.127	12.232	Thor
	34	-0.061	0.209	0.457	-2.085	7.034	Z/F
Tuballoy	23	0.010	0.049	0.222	0.237	1.084	Thor
	23	0.029	0.042	0.205	0.673	0.941	Z/F
Combined Data	277	0.009	0.124	0.352	2.483	34.303	Thor
	277	-0.033	0.085	0.291	-9.270	23.656	Z/F

Table VIb. Comparison of The Mean, Variance, Standard Deviation, Sum and Sum of Squares of The Plate Thickness Relative Error

Target Material	Number	Mean	Variance	Standard Deviation	Σ R.E.	Σ $(R.E.)^2$	
Magnesium	23	0.001	0.107	0.327	0.014	2.349	Thor
	23	0.003	0.115	0.339	0.061	2.531	Z/F
Aluminum	84	-0.135	0.035	0.188	-11.323	4.470	Thor
	84	-0.113	0.026	0.160	-9.473	3.185	Z/F
Titanium	20	0.024	0.072	0.268	0.473	-0.530	Thor
	20	-0.027	0.086	0.293	-0.530	1.650	Z/F
Cast Iron	19	0.020	0.013	0.115	0.371	0.244	Thor
	19	-0.215	0.017	0.131	-4.090	1.189	Z/F
Steel (RHA)	17	-0.353	0.041	0.202	-5.996	2.770	Thor
	17	-0.238	0.023	0.150	-4.053	1.327	Z/F
Steel (FHA)	29	0.024	0.048	0.220	0.684	1.366	Thor
	29	-0.083	0.019	0.138	-2.416	0.738	Z/F
Copper	28	0.017	0.033	0.182	0.483	0.900	Thor
	28	0.208	0.029	0.170	5.836	2.000	Z/F
Lead	34	0.307	0.599	0.774	10.428	22.964	Thor
	34	0.100	0.218	0.467	3.393	7.549	Z/F
Tuballoy	23	0.034	0.217	0.466	0.790	4.798	Thor
	23	0.074	0.186	0.431	1.693	4.212	Z/F
Combined Data	277	-0.015	0.149	0.386	-4.076	41.232	Thor
	277	-0.034	0.087	0.295	-9.579	24.381	Z/F

Table VIc. Comparison of The Mean, Variance, Standard Deviation, Sum and Sum of Squares of The Residual Velocity Deviants

Target Material	Number	Mean	Variance	Standard Deviation	ΣD	ΣD^2	
Magnesium	23	34.4	73596.7	271.3	790.8	1646313.1	Thor
	23	14.6	38264.1	195.6	336.9	846745.9	Z/F
Aluminum	84	-51.9	4577.3	67.7	-4361.4	606365.9	Thor
	84	-39.1	5763.3	75.9	-3286.9	606962.7	Z/F
Titanium	20	42.8	20346.8	142.6	855.3	423167.2	Thor
	20	33.3	23154.6	152.2	665.7	462092.6	Z/F
Cast Iron	19	-0.4	8712.5	93.3	-7.3	156828.0	Thor
	19	-149.8	11266.8	106.1	-2846.8	629338.2	Z/F
Steel (RHA)	17	-119.9	4466.9	66.8	-2039.1	316062.1	Thor
	17	-100.1	5978.1	77.3	-1701.5	265952.4	Z/F
Steel (FHA)	29	-0.7	17081.4	130.7	-19.5	478292.9	Thor
	29	-94.3	37147.3	192.7	-2734.9	1298040.9	Z/F
Copper	28	18.2	12024.6	109.7	510.7	333979.7	Thor
	28	89.2	14203.1	119.2	2497.2	606139.8	Z/F
Lead	34	82.7	60913.1	246.8	2813.4	2224937.2	Thor
	34	34.8	66762.6	258.4	1184.0	2244396.9	Z/F
Tuballoy	23	-23.6	59978.1	244.9	-543.3	1332350.9	Thor
	23	12.7	72507.2	269.3	291.8	1598861.4	Z/F
Combined	277	-7.2	27187.9	164.9	-2000.4	7518297.0	Thor
Data	277	-20.2	30600.0	174.9	-5594.5	8558583.8	Z/F

Table VId. Comparison of The Mean, Variance, Standard Deviation, Sum and Sum of Squares of The Residual Velocity Relative Error

Target Material	Number	Mean	Variance	Standard Deviation	Σ R. E.	Σ (R. E.)^2	
Magnesium	23	0.048	0.383	0.619	1.111	8.482	Thor
	23	0.062	0.259	0.508	1.431	5.778	Z/F
Aluminum	83*	-0.113	0.043	0.207	-9.370	4.577	Thor
	83*	-0.085	0.073	0.270	-7.062	6.596	Z/F
Titanium	20	0.063	0.066	0.258	1.261	1.341	Thor
	20	0.059	0.103	0.321	1.173	2.032	Z/F
Cast Iron	19	-0.003	0.044	0.210	-0.049	0.795	Thor
	19	-0.352	0.041	0.376	-6.688	4.901	Z/F
Steel (RHA)	17	-0.189	0.015	0.121	-3.214	0.844	Thor
	17	-0.139	0.011	0.103	-2.366	0.500	Z/F
Steel (FHA)	26*	-0.049	0.022	0.149	-1.286	0.615	Thor
	28*	-0.237	0.139	0.373	-6.641	5.239	Z/F
Copper	28	0.025	0.021	0.144	0.696	0.576	Thor
	28	0.171	0.031	0.175	4.789	1.646	Z/F
Lead	34	0.166	0.150	0.387	5.664	5.880	Thor
	34	-0.001	0.126	0.355	-0.023	4.156	Z/F
Tuballoy	23	0.023	0.100	0.316	0.530	2.215	Thor
	23	0.025	0.173	0.416	0.578	3.286	Z/F
Combined	273*	-0.017	0.093	0.305	-4.657	25.325	Thor
Data	275*	0.054	0.124	0.352	-14.809	34.764	Z/F

*Does not include data where the residual velocity was zero unless the predicted residual velocity was also zero.

VIII. ANALYZING THE PENETRATION PROCESS

Although the force Equation 3 may not represent reality, it does involve relevant physical parameters. When applied to Newton's equation of motion, the resulting integrated equation does a fair job of predicting plate thickness (or residual velocity as the case may be) over a wide range of target materials. It would be fair to say that the force equation represents an average effect of the resistance to penetration encountered by a projectile. Therefore, it should be possible to learn something about the penetration process.

The equations of Section III can be reduced to the following form:

$$\frac{X_t A}{M_p} = f(\rho_t, H_t, V_s, V_r) .$$

The parameters associated with the projectile (the cross-sectional area, A, and the projectile mass M_p) appear on one side of the equation along with the target plate thickness X_t. This allows generalized curves to be drawn, plotting the values for X_tA/M_p as a function of velocity for particular values of target plate hardness H_t and target density ρ_t.

A family of curves is shown in Figure 2a. The target plate hardness is held constant at BHN 100. Each curve represents a different target plate density. Along the abscissa (the x-axis) is the parameter X_tA/M_p and along the ordinant (the y-axis) is the projectile velocity. The plot can be used in two ways.

First, an estimate of the residual velocity for a given striking velocity can be made by finding the point on the curve corresponding to the striking velocity, then following the curve for a distance in the x direction corresponding to the computed value for X_tA/M_p and then reading the residual velocity off of the y-axis. For example:

Given: $X_t = 1.5$ cm.

H_T = BHN 100 = 9.8×10^9 dynes/cm^2

$A = 2.5$ cm^2

V_s = 2500 m/s = 250000 cm/sec

$\rho_t = 2.77$ g/cc (aluminum)

$M_p = 2.2$ grams.

Find the residual velocity where $X_tA/M_p = \frac{(1.5)(2.5)}{2.2} = 1.70$ by referring to Figure 3a.

Proceeding over 1.70 units in the x-direction along the curve for

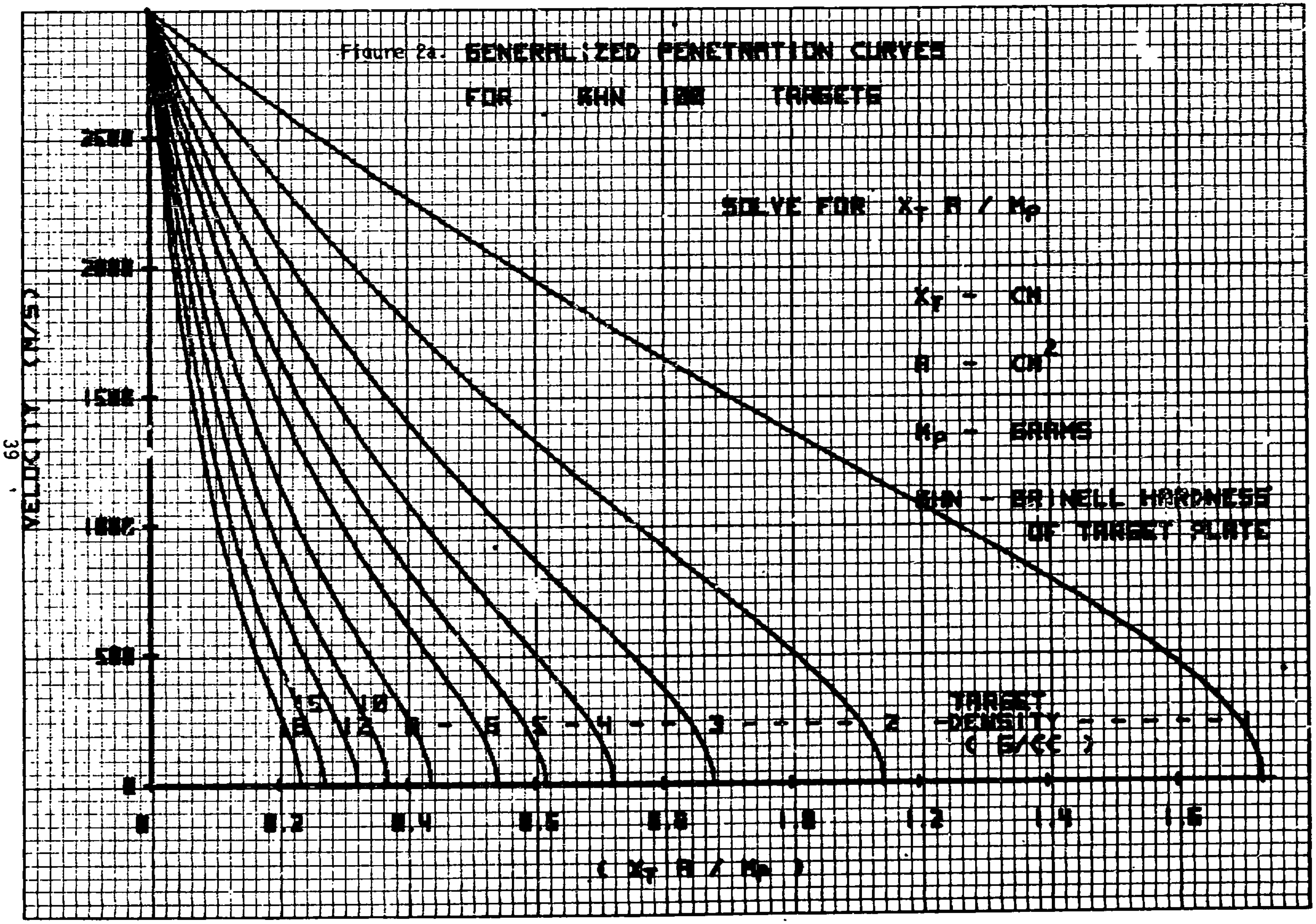


Figure 2a. GENERALIZED PENETRATION CURVES FOR BHN 100 TARGETS

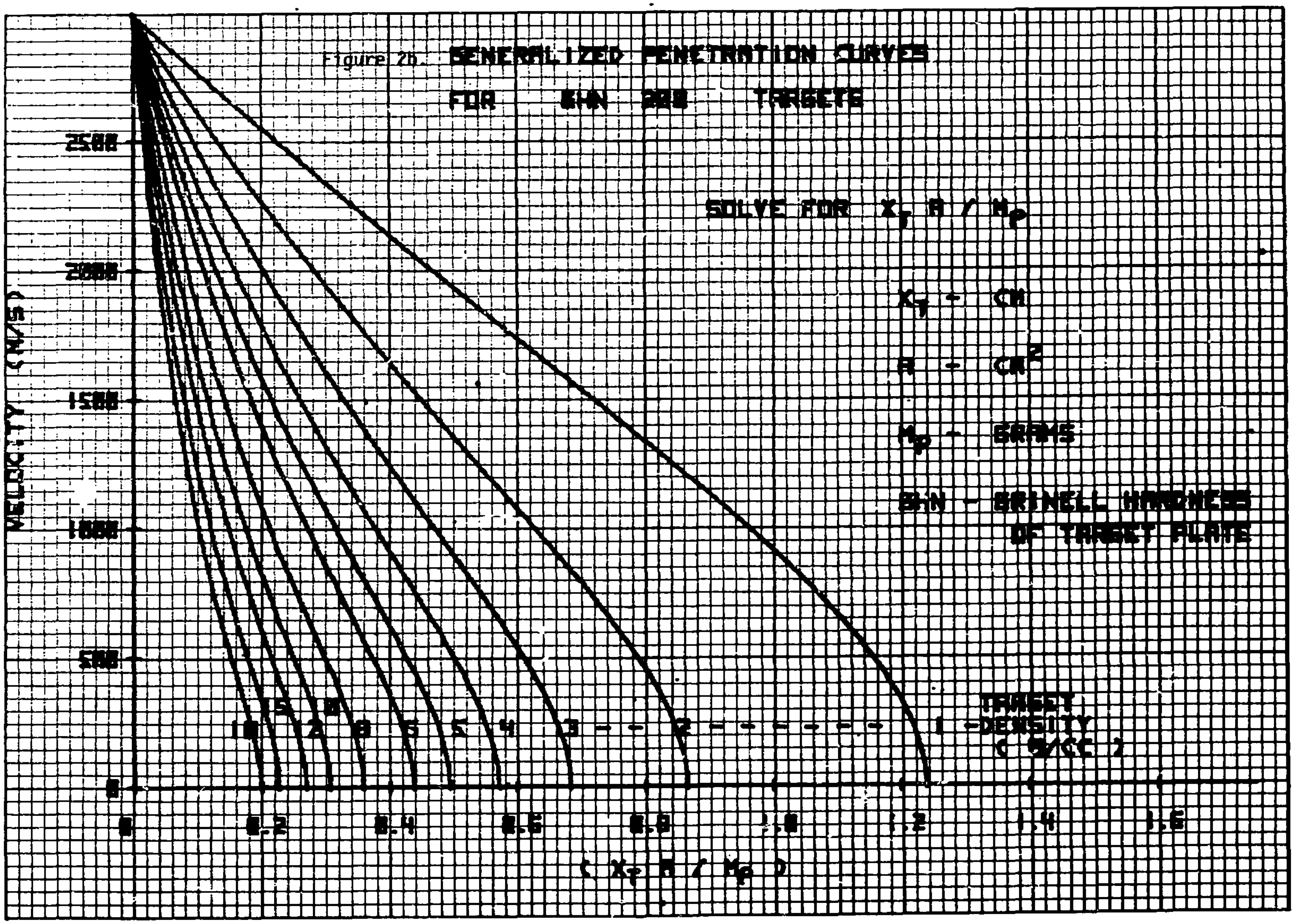


Figure 2b. GENERALIZED PENETRATION CURVES FOR BHN 300 TARGETS

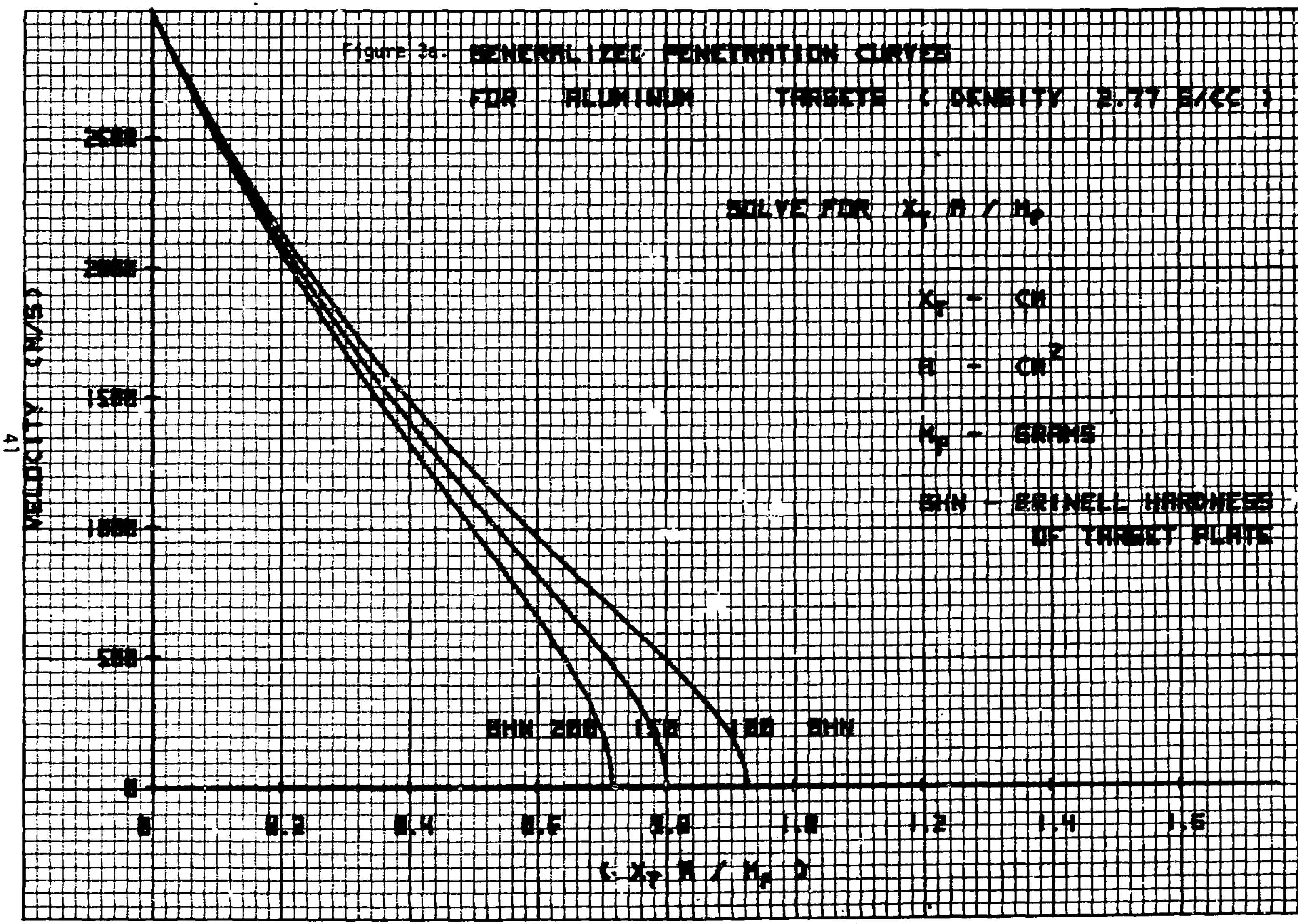


Figure 3a. GENERALIZED PENETRATION CURVES
FOR ALUMINUM TARGETS (DENSITY 2.77 G/CC)
SOLVE FOR X_f A / M_p
X_f - CM
A - CM^2
M_p - GRAMS
BHN - BRINELL HARDNESS
OF TARGET PLATE
BHN 200 150 100 BHN
0
500
1000
1500
2000
2500
VELOCITY (M/S)
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
(X_f A / M_p)

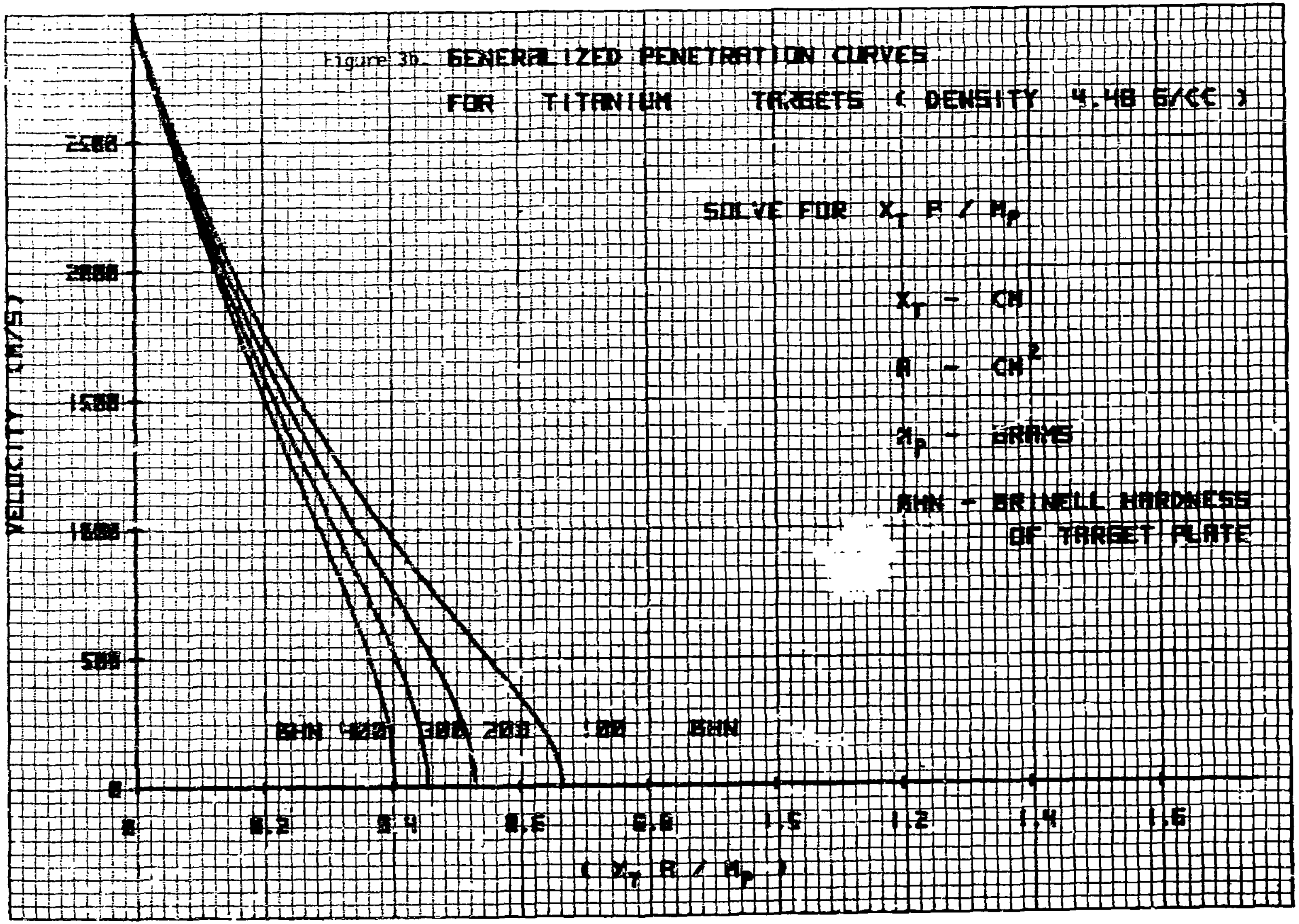


Figure 3b. GENERALIZED PENETRATION CURVES
FOR TITANIUM TARGETS (DENSITY 4.48 G/CC)
SOLVE FOR X_T R / M_p
X_T - CM
R - CM^2
M_p - GRAMS
BHN - BRINELL HARDNESS
OF TARGET PLATE
BHN 400 300 200 100 BHN
VELOCITY (M/S)
2500
2000
1500
1000
500
0
0.2
0.4
0.6
0.8
1.2
1.4
1.6
(X_T R / M_p)

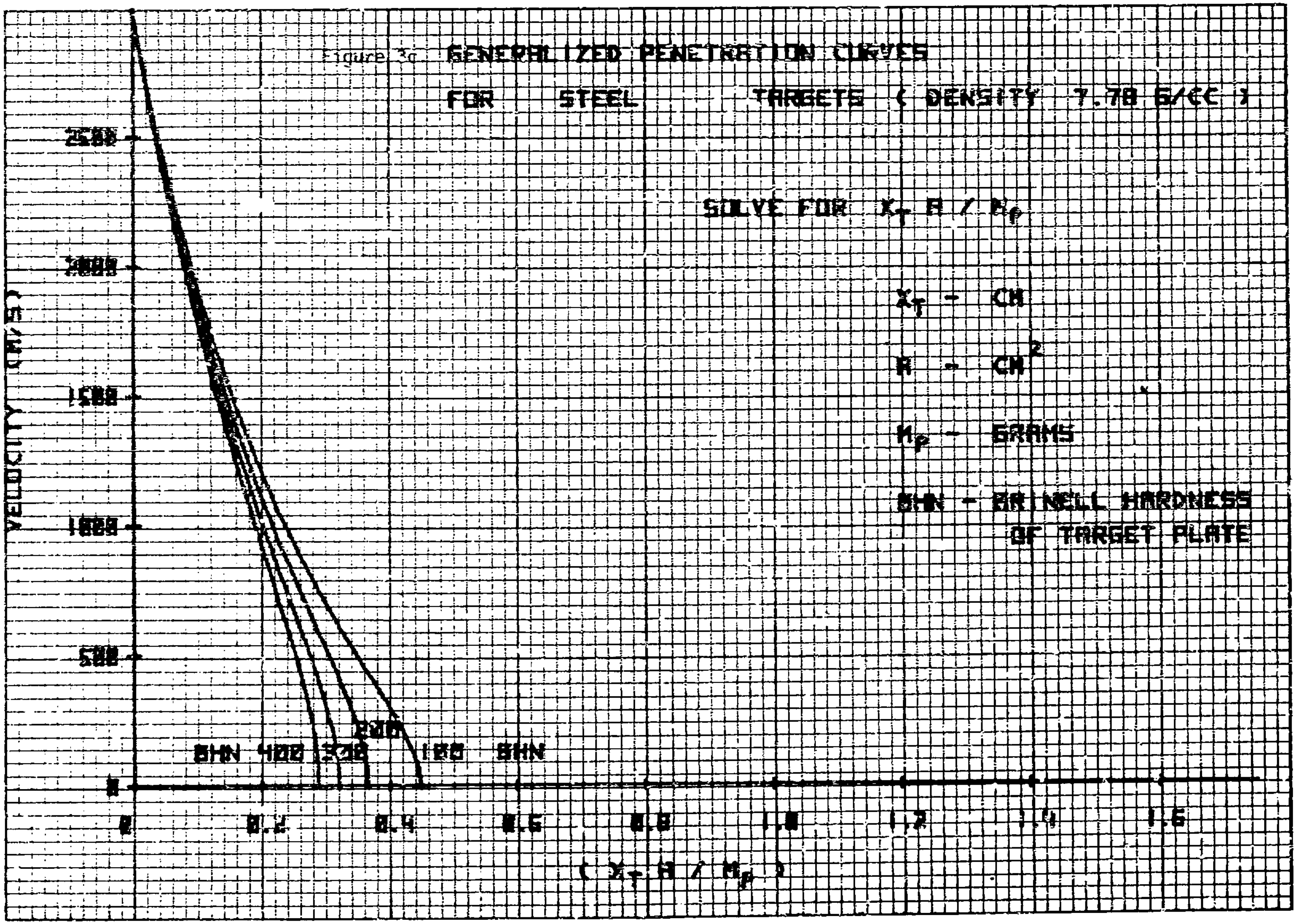


Figure 3c GENERALIZED PENETRATION CURVES
FOR STEEL TARGETS (DENSITY 7.78 G/CC)
SOLVE FOR X_T A / M_p
X_T - CM
A - CM^2
M_p - GRAMS
BHN - BRINELL HARDNESS OF TARGET PLATE
BHN 400
300
200
100 BHN
VELOCITY (M/S)
0
500
1000
1500
2000
2500
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
(X_T A / M_p)

aluminum (BHN 100) beginning at the point for 2500 m/s yields a value for velocity which is less than zero. That is, the projectile would not be able to penetrate 1.5 cm. Changing X_t to 0.5 cm yields a new value of 0.568. Using this value results in an approximate residual velocity of V_r = 780 m/s.

The second way these curves can be utilized is to estimate the limit velocity, i.e., the striking velocity required for the projectile to travel completely through the target with zero residual velocity. For the second case in the example above, where X_tA/M_p = 0.568, the limit velocity is found by going to the left 0.568 units along the x-axis from where the curve for aluminum meets the axis and finding the corresponding x-point on the curve and then reading the velocity value on the y-axis. In this example, the limit velocity is approximately 1630 m/s. Greater precision (mathematically) can be obtained by substituting the appropriate values into Equation 16.

It should be noted in Figure 2a, Figure 2b (which is similar to 2a except the hardness is held constant at BHN 200) and in Figures 3a, b and c that the slope of each curve becomes more negative as the velocity decreases and changes dramatically as the velocity approaches zero. The latter is caused by the static component of the force equation dominating the other two terms. This explains why it is not possible to linearly extrapolate limit velocities from residual velocity data.

It should also be noted that the variation of penetration with respect to target plate density is non-linear. There is greater variation for a change in less dense materials than a corresponding change in the more dense materials. For example, a velocity change from 2500 m/s to 2000 m/s yields the following:

Density	X_tA/M_p	ρ_tX_tA/M_p
1 g/cc	0.300	0.300
2 g/cc	0.175	0.350
4 g/cc	0.095	0.380
8 g/cc	0.052	0.416.

If the variation were linear, the values in the third column would be identical. A non-linear effect can also be seen in Figures 3a, b and c with respect to target plate hardness for a given plate density. Hence, the homogeneity of the target with respect to hardness and density determines to a great extent the replicability of a given set of experimental conditions.

The single most important geometric variable of the projectile parameters is the projected cross-sectional area of the projectile at impact. The yaw angle is difficult to control and to determine with the exception of spheres and spin stabilized projectiles. Any change

in the yaw angle results in a new cross-sectional area since it is the projected area of the projectile onto the surface of the target plate that is required.

When considering the ability of the projectile, as a whole, to penetrate a target, the important parameter is the ratio of the projectile mass to its area. Shaped charges are capable of deep penetrations because they have a large mass per unit area ratio.

IX. SUMMARY AND FUTURE AREAS OF INVESTIGATION

An analytic model of kinetic energy round penetration has been presented. This model compares favorably with the Thor equation in predicting residual velocity for a projectile-target interaction. It is more general in its application than the Thor equation and can be used to study the penetration process.

An extension will be made to include oblique attack angles. A preliminary approach will be to adopt the same method as the Thor approach, i.e., multiplying by the secant of the angle raised to some power $(\sec \theta)^f$. Something more complex may be required to adequately predict the effect of oblique angles.

Another area of investigation is predicting projectile breakup and predicting residual masses. This information can then be used to predict penetration of a secondary target plate.

ACKNOWLEDGMENT

The author acknowledges the assistance of Dr. Charles Anderson in the preparation of this report and to Mr. Thomas Jeter, Mr. John Kineke and Mr. John Polk, all in the Fragmentation Branch of Warhead Mechanics Division, for reviewing the report for comprehensiveness and accuracy.

APPENDIX A

PROJECTILE-TARGET PENETRATION DATA

All values reported in Reference 2 appearing in this appendix have been converted from the British system of units to the metric system with the exception of the Brinell hardness numbers which were already in the metric system.

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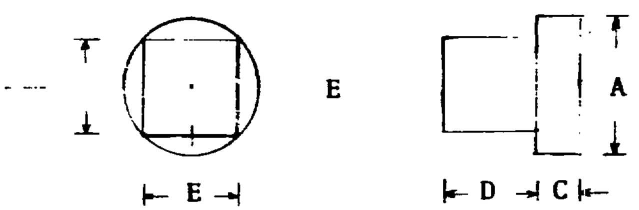
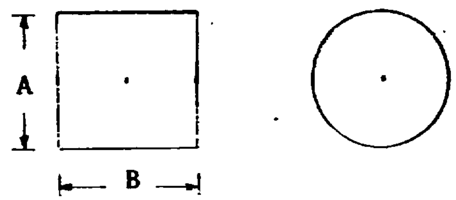
Fragment Dimensions

Type I



Type II



Type	A	B	C	D	E	Mass (Grams)
I	1.491	1.471	0.572	0.899	1.052	15.564
I	1.267	0.988	0.432	0.556	0.897	7.782
I	1.013	0.770	0.333	0.437	0.716	3.891
I	0.759	0.716	0.292	0.424	0.536	1.946
I	0.592	0.584	0.236	0.348	0.424	0.973
II	1.491	1.143				15.564
II	1.267	0.795				7.782
II	1.013	0.617				3.891
II	0.759	0.541				1.946
II	0.592	0.457				0.973
II	1.745	1.661				30.804

All dimensions are in cms. Fragments made of SAE 1020 Steel

Target Materials

Name	Identification	Density (g/cc)	BHN
Magnesium Alloys	FS-1 (Dow Chemical), AZ92	1.76, 1.83	72
Aluminum Alloys	2024T-3 and 2024T-4	2.77	120
Titanium Alloys	Ti 6Al 4V; Ti 7 Mn	4.42, 4.55	190
Cast Iron	Ductile Nodular Graphitic (60-45-18) ASTM-A339-51T	7.21	150-220
Face-Hardened Steel		7.78	(Front) 480-550 (Rear) 331-375
Homogeneous Steel (a) Mild (b) Hard		7.78	 ~ 150 ~ 380
Copper	Elec. Tough Pitch; QQC-502	8.91	42
Lead	Comm. Pure (No Sb) B-29-40-I	11.01	5.5
Tuballoy	Depleted Uranium or U238	18.71	235-245

PENETRATION DATA

TARGET= MAGNESIUM ALLOY DENSITY= 1.80 G/CC

NR	NOMINAL HARDNESS (KG/MM2)	THICKNESS (CM)	OBLIQUITY (DEG)	PROJECTILE MASS (GRAMS)	PROJECTILE DIAMETER (CM)	PROJECTILE AREA (CM2)	SPEED STRIKING (M/S)	SPEED RESIDUAL (M/S)	PRIMARY RESIDUAL MASS (GRAMS)	HOLE AREA (CM2)
1	72.0	.318	.0	1.950	.759	.452	696.5	487.1	1.880	***
2	72.0	.765	.0	1.950	.759	.452	919.3	632.5	1.660	***
3	72.0	1.270	.0	1.950	.759	.452	1488.6	783.9	1.850	***
4	72.0	2.540	.0	1.950	.759	.452	1373.4	603.2	1.640	***
5	72.0	2.540	.0	1.950	.759	.452	1828.5	419.1	1.500	***
6	72.0	2.540	.0	1.950	.759	.452	2497.5	993.9	.660	***
7	72.0	2.540	.0	1.950	.759	.452	2890.7	1164.9	.590	***
8	72.0	.765	.0	3.890	1.013	.806	959.8	680.9	3.830	***
9	72.0	1.270	.0	3.890	1.013	.806	1206.1	842.2	3.580	***
10	72.0	1.270	.0	3.890	1.013	.806	1211.3	860.5	3.550	***
11	72.0	2.540	.0	3.890	1.013	.806	1244.8	447.4	3.750	***
12	72.0	.765	.0	7.780	1.267	1.261	877.2	738.5	7.720	***
13	72.0	1.270	.0	7.780	1.267	1.261	1149.7	968.5	***	***
14	72.0	1.905	.0	7.780	1.267	1.261	1382.6	1079.0	5.050	***
15	72.0	2.540	.0	7.780	1.267	1.261	1485.0	620.8	6.780	***
16	72.0	5.080	.0	7.780	1.267	1.261	1478.0	199.3	7.000	***
17	72.0	5.080	.0	7.780	1.267	1.261	2218.9	237.7	***	***
18	72.0	1.270	.0	15.560	1.491	1.746	1439.3	1239.0	***	***
19	72.0	1.905	.0	15.560	1.491	1.746	1530.4	1201.5	13.110	***
20	72.0	2.540	.0	15.560	1.491	1.746	1410.3	980.9	14.320	***
21	72.0	2.540	.0	15.560	1.491	1.746	1417.0	537.7	13.920	***
22	72.0	5.080	.0	15.560	1.491	1.746	1438.1	572.7	12.860	***
23	72.0	7.620	.0	15.560	1.491	1.746	3170.8	1275.9	***	***

PENETRATION DATA

TARGET= ALUMINUM 2024T3 DENSITY= 2.77 G/CC

NR	NOMINAL HARDNESS (KG/MM2)	THICKNESS (CM)	OBLIQUITY (DEG)	PROJECTILE MASS (GRAMS)	PROJECTILE DIAMETER (CM)	PROJECTILE AREA (CM2)	SPEED STRIKING (M/S)	SPEED RESIDUAL (M/S)	PRIMARY RESIDUAL MASS (GRAMS)	HOLE AREA (CM2)
1	120.0	.318	.0	1.950	.759	.452	338.0	260.3	***	***
2	120.0	.318	.0	1.950	.759	.452	545.9	396.9	***	***
3	120.0	.318	.0	1.950	.759	.452	912.0	723.0	***	***
4	120.0	.318	.0	1.950	.759	.452	1115.9	952.2	***	***
5	120.0	.478	.0	1.950	.759	.452	545.9	312.1	***	***
6	120.0	.478	.0	1.950	.759	.452	872.3	576.1	***	***
7	120.0	.478	.0	1.950	.759	.452	880.6	629.1	***	***
8	120.0	.478	.0	1.950	.759	.452	881.8	620.3	***	***
9	120.0	.478	.0	1.950	.759	.452	1182.6	920.8	***	***
10	120.0	.478	.0	1.950	.759	.452	1616.0	1357.9	***	***
11	120.0	.478	.0	1.950	.759	.452	1542.3	1385.9	***	***
12	120.0	.635	.0	1.950	.759	.452	597.7	289.3	***	***
13	120.0	.635	.0	1.950	.759	.452	607.8	296.3	***	***
14	120.0	.635	.0	1.950	.759	.452	613.9	289.9	***	***
15	120.0	.635	.0	1.950	.759	.452	1016.2	643.1	***	***
16	120.0	.635	.0	1.950	.759	.452	1022.9	640.1	***	***
17	120.0	.635	.0	1.950	.759	.452	1067.4	653.8	***	***
18	120.0	.635	.0	1.950	.759	.452	1425.6	1013.4	***	***
19	120.0	.635	.0	1.950	.759	.452	1432.9	1029.0	***	***
20	120.0	.635	.0	1.950	.759	.452	1446.9	1052.5	***	***
21	120.0	1.270	.0	1.950	.759	.452	1154.0	330.1	***	***
22	120.0	1.270	.0	1.950	.759	.452	1160.7	346.0	***	***
23	120.0	1.270	.0	1.950	.759	.452	1442.3	691.0	***	***
24	120.0	1.270	.0	1.950	.759	.452	1394.8	627.0	***	***
25	120.0	.635	.0	3.890	1.013	.806	633.4	377.9	***	***
26	120.0	.635	.0	3.890	1.013	.806	727.9	458.1	***	***
27	120.0	.635	.0	3.890	1.013	.806	981.2	565.1	***	***
28	120.0	.635	.0	3.890	1.013	.806	1167.1	881.2	***	***
29	120.0	.635	.0	3.890	1.013	.806	1229.3	911.7	***	***
30	120.0	.635	.0	3.890	1.013	.806	1481.3	1196.3	***	***
31	120.0	1.270	.0	3.890	1.013	.806	935.9	282.9	***	***
32	120.0	1.270	.0	3.890	1.013	.806	1087.5	404.8	***	***
33	120.0	1.270	.0	3.890	1.013	.806	1679.2	832.1	***	***
34	120.0	1.270	.0	3.890	1.013	.806	1490.5	869.0	***	***
35	120.0	1.905	.0	3.890	1.013	.806	1476.8	360.5	***	***

PENETRATION DATA

TARGET= ALUMINUM 2024T3 DENSITY= 2.77 G/CC

NR	NOMINAL HARDNESS (KG/MM2)	THICKNESS (CM)	OBLIQUITY (DEG)	PROJECTILE MASS (GRAMS)	PROJECTILE DIAMETER (CM)	PROJECTILE AREA (CM2)	SPEED STRIKING (M/S)	SPEED RESIDUAL (M/S)	PRIMARY RESIDUAL MASS (GRAMS)	HOLE AREA (CM2)
36	120.0	1.905	.0	3.890	1.013	.806	1483.2	433.1	***	***
37	120.0	.318	.0	7.780	1.267	1.261	557.2	448.4	***	***
38	120.0	.318	.0	7.780	1.267	1.261	917.8	821.1	***	***
39	120.0	.318	.0	7.780	1.267	1.261	1200.6	1054.9	***	***
40	120.0	.478	.0	7.780	1.267	1.261	580.3	445.0	***	***
41	120.0	.478	.0	7.780	1.267	1.261	924.8	771.4	***	***
42	120.0	.478	.0	7.780	1.267	1.261	1197.9	1033.3	***	***
43	120.0	.635	.0	7.780	1.267	1.261	542.2	379.5	***	***
44	120.0	.635	.0	7.780	1.267	1.261	552.6	405.7	***	***
45	120.0	.635	.0	7.780	1.267	1.261	942.4	712.9	***	***
46	120.0	.635	.0	7.780	1.267	1.261	1037.2	774.5	***	***
47	120.0	.635	.0	7.780	1.267	1.261	1521.9	1282.3	***	***
48	120.0	.635	.0	7.780	1.267	1.261	1569.1	1333.2	***	***
49	120.0	.635	.0	7.780	1.267	1.261	1583.7	1278.9	***	***
50	120.0	1.270	.0	7.780	1.267	1.261	1050.3	537.7	***	***
51	120.0	1.270	.0	7.780	1.267	1.261	1069.5	546.1	***	***
52	120.0	1.270	.0	7.780	1.267	1.261	1503.3	983.3	***	***
53	120.0	1.270	.0	7.780	1.267	1.261	1524.3	993.0	***	***
54	120.0	1.905	.0	7.780	1.267	1.261	1006.5	201.5	***	***
55	120.0	1.905	.0	7.780	1.267	1.261	1061.3	158.8	***	***
56	120.0	1.905	.0	7.780	1.267	1.261	1506.3	658.1	***	***
57	120.0	1.905	.0	7.780	1.267	1.261	1521.0	665.6	***	***
58	120.0	.478	.0	15.560	1.491	1.746	1739.5	1584.7	***	***
59	120.0	.478	.0	15.560	1.491	1.746	1776.4	1574.9	***	***
60	120.0	.478	.0	15.560	1.491	1.746	1791.3	1610.3	***	***
61	120.0	.635	.0	15.560	1.491	1.746	602.9	513.6	***	***
62	120.0	.635	.0	15.560	1.491	1.746	634.9	530.1	***	***
63	120.0	.635	.0	15.560	1.491	1.746	1095.5	919.6	***	***
64	120.0	.635	.0	15.560	1.491	1.746	1119.2	946.4	***	***
65	120.0	.635	.0	15.560	1.491	1.746	1488.6	1295.7	***	***
66	120.0	.635	.0	15.560	1.491	1.746	1496.0	1319.4	***	***
67	120.0	1.270	.0	15.560	1.491	1.746	630.9	350.8	***	***
68	120.0	1.270	.0	15.560	1.491	1.746	633.7	360.6	***	***
69	120.0	1.270	.0	15.560	1.491	1.746	1060.4	724.8	***	***
70	120.0	1.270	.0	15.560	1.491	1.746	1067.7	714.4	***	***
71	120.0	1.270	.0	15.560	1.491	1.746	1495.0	1175.6	***	***

PENETRATION DATA

TARGET= ALUMINUM 2024T3 DENSITY= 2.77 G/CC

NR	NOMINAL HARDNESS (KG/MM2)	THICKNESS (CM)	OBLIQUITY (DEG)	PROJECTILE MASS (GRAMS)	PROJECTILE DIAMETER (CM)	PROJECTILE AREA (CM2)	SPEED STRIKING (M/S)	SPEED RESIDUAL (M/S)	PRIMARY RESIDUAL MASS (GRAMS)	HOLE AREA (CM2)
72	120.0	1.270	.0	15.560	1.491	1.746	1496.0	1138.7	***	***
73	120.0	1.905	.0	15.560	1.491	1.746	1343.0	532.5	***	***
74	120.0	1.905	.0	15.560	1.491	1.746	1366.8	493.2	***	***
75	120.0	1.905	.0	15.560	1.491	1.746	1381.1	533.4	***	***
76	120.0	1.905	.0	15.560	1.491	1.746	1496.9	950.7	***	***
77	120.0	1.905	.0	15.560	1.491	1.746	1505.7	940.6	***	***
78	120.0	2.540	.0	15.560	[illegible]	1.746	975.4	.0	***	***
79	120.0	2.540	.0	15.560	[illegible]	1.746	1061.6	229.8	***	***
80	120.0	2.540	.0	15.560	[illegible]	1.746	1067.4	245.7	***	***
81	120.0	2.540	.0	15.560	1.491	1.746	1069.2	150.3	***	***
82	120.0	2.540	.0	15.560	1.491	1.746	1393.0	215.2	***	***
83	120.0	2.540	.0	15.560	1.491	1.746	1508.5	666.6	***	***
84	120.0	2.540	.0	15.560	1.491	1.746	1517.9	673.3	***	***

PENETRATION DATA

TARGET= TITANIUM ALLOY DENSITY= 4.46 G/CC

NR	NOMINAL HARDNESS (KG/MM2)	THICKNESS (CM)	OBLIQUITY (DEG)	PROJECTILE MASS (GRAMS)	PROJECTILE DIAMETER (CM)	PROJECTILE AREA (CM2)	SPEED STRIKING (M/S)	SPEED RESIDUAL (M/S)	PRIMARY RESIDUAL MASS (GRAMS)	HOLE AREA (CM2)
1	190.0	.127	.0	1.950	.759	.452	567.8	521.2	1.880	***
2	190.0	.127	.0	1.950	.759	.452	1461.8	1294.2	.910	***
3	190.0	.318	.0	1.950	.759	.452	880.3	590.4	***	***
4	190.0	.318	.0	1.950	.759	.452	1355.5	1083.6	1.630	***
5	190.0	.635	.0	1.950	.759	.452	1491.1	683.4	1.730	***
6	190.0	.635	.0	1.950	.759	.452	1986.4	1127.1	.560	***
7	190.0	1.270	.0	1.959	.759	.452	2371.7	381.6	***	***
8	190.0	.127	.0	3.890	1.013	.806	798.9	672.7	3.830	***
9	190.0	.127	.0	3.890	1.013	.806	1032.7	957.7	1.720	***
10	190.0	.318	.0	3.890	1.013	.806	620.3	500.5	3.830	***
11	190.0	.318	.0	3.890	1.013	.806	773.3	582.8	3.810	***
12	190.0	.318	.0	3.890	1.013	.806	1499.0	1251.8	2.430	***
13	190.0	.635	.0	3.890	1.013	.806	1505.7	774.5	3.240	***
14	190.0	.635	.0	3.890	1.013	.806	1526.1	979.3	***	***
15	190.0	.635	.0	3.890	1.013	.806	2455.2	1367.3	.120	***
16	190.0	1.270	.0	3.890	1.013	.806	2551.8	1165.9	.570	***
17	190.0	.127	.0	7.780	1.267	1.261	641.0	561.4	7.720	***
18	190.0	.127	.0	7.780	1.267	1.261	959.2	874.8	7.720	***
19	190.0	.318	.0	7.780	1.267	1.261	976.0	785.5	7.720	***
20	190.0	.635	.0	7.780	1.267	1.261	1484.4	994.9	***	***

PENETRATION DATA

TARGET= CAST IRON DENSITY= 7.21 G/CC

NR	NOMINAL HARDNESS (KG/MM²)	THICKNESS (CM)	OBLIQUITY (DEG)	PROJECTILE MASS (GRAMS)	PROJECTILE DIAMETER (CM)	PROJECTILE AREA (CM²)	SPEED STRIKING (M/S)	SPEED RESIDUAL (M/S)	PRIMARY RESIDUAL MASS (GRAMS)	HOLE AREA (CM²)
1	185.0*	.478	.0	.97	.592	.275	1315.5	570.6	.700	***
2	185.0	.478	.0	1.950	.759	.452	573.0	193.2	1.910	***
3	185.0	.478	.0	1.950	.759	.452	1183.2	667.8	1.510	***
4	185.0	.478	.0	1.950	.759	.452	1735.2	1149.1	.890	***
5	185.0	.953	.0	1.950	.759	.452	1194.8	148.1	1.580	***
6	185.0	.953	.0	1.950	.759	.452	1761.1	552.0	.220	***
7	185.0	.478	.0	3.890	1.013	.806	624.8	378.9	3.830	***
8	185.0	.478	.0	3.890	1.013	.806	1295.4	894.3	3.250	***
9	185.0	.478	.0	3.890	1.013	.806	1862.0	1304.9	2.370	***
10	185.0	.953	.0	3.890	1.013	.806	1249.4	357.2	2.720	***
11	185.0	.953	.0	3.890	1.013	.806	1775.8	755.0	2.090	***
12	185.0	1.427	.0	3.890	1.013	.806	1774.6	400.5	1.570	***
13	185.0	.478	.0	15.560	1.491	1.746	607.8	424.3	15.290	***
14	185.0	.478	.0	15.560	1.491	1.746	1063.1	851.9	13.940	***
15	185.0	.478	.0	15.560	1.491	1.746	1592.3	1307.9	11.870	***
16	185.0	.953	.0	15.560	1.491	1.746	1185.7	702.3	12.600	***
17	185.0	.953	.0	15.560	1.491	1.746	1862.0	1079.6	11.080	***
18	185.0	1.427	.0	15.560	1.491	1.746	1236.6	486.2	11.850	***
19	185.0	1.427	.0	15.560	1.491	1.746	1815.7	809.9	7.840	***

* ACTUAL HARDNESS VARIES FROM 15[illegible] TO 220 BHN.

PENETRATION DATA

TARGET= ROLLED HOMOGENEOUS STEEL DENSITY= 7.73 G/CC

NR	NOMINAL HARDNESS (KG/MM2)	THICKNESS (CM)	OBLIQUITY (DEG)	PROJECTILE MASS (GRAMS)	PROJECTILE DIAMETER (CM)	PROJECTILE AREA (CM2)	SPEED STRIKING (M/S)	SPEED RESIDUAL (M/S)	PRIMARY RESIDUAL MASS (GRAMS)	HOLE AREA (CM2)
1	135.0	.046	.0	1.950	.759	.452	888.5	848.9	***	***
2	135.0	.152	.0	1.950	.759	.452	1211.6	1015.0	***	***
3	300.0	.318	.0	1.950	.759	.452	1521.3	1196.3	***	***
4	305.0	.635	.0	1.950	.759	.452	1394.5	460.3	***	***
5	393.0	.152	.0	1.950	.759	.452	609.9	367.9	***	***
6	135.0	.046	.0	3.890	1.013	.806	302.1	277.4	***	***
7	135.0	.152	.0	3.890	1.013	.806	393.5	256.0	***	***
8	135.0	.318	.0	3.890	1.013	.806	883.6	542.5	***	***
9	300.0	.318	.0	3.890	1.013	.806	879.6	583.7	***	***
10	300.0	.318	.0	3.890	1.013	.806	1466.1	1164.3	***	***
11	300.0	.635	.0	3.890	1.013	.806	1466.1	687.3	***	***
12	300.0	.318	.0	7.780	1.267	1.261	909.5	690.4	***	***
13	300.0	.318	.0	15.560	1.491	1.746	916.5	754.4	***	***
14	300.0	.318	.0	15.560	1.491	1.746	1425.6	1179.6	***	***
15	300.0	.635	.0	15.560	1.491	1.746	1432.6	1037.8	***	***
16	305.0	.635	.0	15.560	1.491	1.746	1556.0	1109.5	***	***
17	332.0	1.270	.0	15.560	1.491	1.746	1660.5	759.6	***	***

PENETRATION DATA

TARGET= FACE HARDENED STEEL DENSITY= 7.78 G/CC

NR	NOMINAL HARDNESS (KG/MM2)	THICKNESS (CM)	OBLIQUITY (DEG)	PROJECTILE MASS (GRAMS)	PROJECTILE DIAMETER (CM)	PROJECTILE AREA (CM2)	SPEED STRIKING (M/S)	SPEED RESIDUAL (M/S)	PRIMARY RESIDUAL MASS (GRAMS)	HOLE AREA (CM2)
1	400.0 *	.635	.0	.973	.592	.275	2207.7	566.6	.130	***
2	400.0	.345	.0	1.950	.759	.452	748.3	.0	***	***
3	400.0	.345	.0	1.950	.759	.452	1017.4	372.2	1.650	.593
4	400.0	.345	.0	1.950	.759	.452	1081.7	.0	1.570	.710
5	400.0	.635	.0	1.950	.759	.452	1765.1	551.1	.840	***
6	400.0	.635	.0	1.950	.759	.452	1319.7	716.6	.430	***
7	400.0	.635	.0	1.950	.759	.452	2881.6	1115.9	.060	1.606
8	400.0	.635	.0	1.950	.759	.452	2936.1	1263.4	.220	1.606
9	400.0	.635	.0	3.890	1.013	.806	1066.8	.0	.000	***
10	400.0	.635	.0	3.890	1.013	.806	1163.7	331.0	1.990	***
11	400.0	.635	.0	3.890	1.013	.806	1785.9	767.2	.360	***
12	400.0	.635	.0	3.890	1.013	.806	2151.3	901.3	.690	1.981
13	400.0	.635	.0	3.890	1.013	.806	2799.3	1514.6	.310	1.981
14	400.0	1.270	.0	3.890	1.013	.806	1791.0	.0	.000	***
15	400.0	1.270	.0	3.890	1.013	.806	2275.6	304.8	1.150	2.396
16	400.0	1.270	.0	3.890	1.013	.806	2693.8	693.7	.130	1.981
17	400.0	.635	.0	7.780	1.267	1.261	1150.9	483.7	6.450	***
18	400.0	.635	.0	7.780	1.267	1.261	1766.0	870.5	1.390	***
19	400.0	.635	.0	7.780	1.267	1.261	1997.4	960.1	.600	8.326
20	400.0	.635	.0	7.780	1.267	1.261	2985.2	2043.4	.220	5.063
21	400.0	1.270	.0	7.780	1.267	1.261	1802.0	369.1	6.560	***
22	400.0	1.270	.0	7.780	1.267	1.261	2086.4	525.5	.730	3.091
23	400.0	1.270	.0	7.780	1.267	1.261	2225.0	765.7	1.000	3.323
24	400.0	1.270	.0	7.780	1.267	1.261	2381.3	978.4	.400	3.878
25	400.0	.635	.0	15.560	1.491	1.746	1190.6	699.2	9.470	***
26	400.0	.635	.0	15.560	1.491	1.746	1536.5	1039.4	1.530	***
27	400.0	1.270	.0	15.560	1.491	1.746	1200.3	289.6	12.310	***
28	400.0	1.270	.0	15.560	1.491	1.746	1839.8	710.2	7.480	***
29	400.0	1.270	.0	15.560	1.491	1.746	2753.0	1351.5	.490	***

* ACTUAL HARDNESS FRONT SURFACE 480 - 550 BHN, REAR SURFACE 331 - 375 BHN

PENETRATION DATA

TARGET= COPPER DENSITY= 8.91 G/CC

NR	NOMINAL HARDNESS (KG/MM2)	THICKNESS (CM)	OBLIQUITY (DEG)	PROJECTILE MASS (GRAMS)	PROJECTILE DIAMETER (CM)	PROJECTILE AREA (CM2)	SPEED STRIKING (M/S)	SPEED RESIDUAL (M/S)	PRIMARY RESIDUAL MASS (GRAMS)	HOLE AREA (CM2)
1	42.0	.152	.0	.970	.592	.275	413.6	239.6	***	***
2	42.0	.152	.0	.970	.592	.275	862.0	611.1	.910	***
3	42.0	.152	.0	.970	.592	.275	1446.0	1107.0	***	***
4	42.0	.318	.0	.970	.592	.275	849.2	410.6	.910	***
5	42.0	.318	.0	.970	.592	.275	1438.7	906.5	.650	***
6	42.0	.635	.0	.970	.592	.275	3227.5	962.9	***	***
7	42.0	.318	.0	1.950	.759	.452	775.1	440.1	1.780	***
8	42.0	.635	.0	1.950	.759	.452	1170.4	666.0	1.880	***
9	42.0	.635	.0	1.950	.759	.452	3480.2	1325.3	***	***
10	42.0	1.270	.0	1.950	.759	.452	2674.9	385.9	.210	***
11	42.0	1.270	.0	1.950	.759	.452	3209.2	467.6	.060	***
12	42.0	.152	.0	3.890	1.013	.806	368.8	265.2	3.830	***
13	42.0	.152	.0	3.890	1.013	.806	790.4	622.7	3.520	***
14	42.0	.318	.0	3.890	1.013	.806	1131.7	804.7	3.520	***
15	42.0	1.270	.0	3.890	1.013	.806	1508.8	278.9	3.830	***
16	42.0	1.270	.0	3.890	1.013	.806	3312.0	799.8	.180	***
17	42.0	.152	.0	7.780	1.267	1.261	349.3	261.2	7.720	***
18	42.0	.318	.0	7.780	1.267	1.261	745.5	501.7	7.460	***
19	42.0	.635	.0	7.780	1.267	1.261	912.3	392.6	7.720	***
20	42.0	1.270	.0	7.780	1.267	1.261	1524.3	377.0	.350	***
21	42.0	1.270	.0	7.780	1.267	1.261	2635.0	861.1	***	***
22	42.0	.152	.0	15.560	1.491	1.746	401.7	331.3	15.500	***
23	42.0	.318	.0	15.560	1.491	1.746	463.9	325.5	***	***
24	42.0	.635	.0	15.560	1.491	1.746	1020.2	705.6	12.750	***
25	42.0	1.270	.0	15.560	1.491	1.746	1403.3	607.8	15.500	***
26	42.0	1.270	.0	15.560	1.491	1.746	1438.1	559.0	***	***
27	42.0	2.540	.0	15.560	1.491	1.746	1565.2	224.0	***	***
28	42.0	2.540	.0	15.560	1.491	1.746	1575.5	226.5	***	***

PENETRATION DATA

TARGET= LEAD DENSITY= 11.01 G/CC

NR	NOMINAL HARDNESS (KG/MM2)	THICKNESS (CM)	OBLIQUITY (DEG)	PROJECTILE MASS (GRAMS)	PROJECTILE DIAMETER (CM)	PROJECTILE AREA (CM2)	SPEED STRIKING (M/S)	SPEED RESIDUAL (M/S)	PRIMARY RESIDUAL MASS (GRAMS)	HOLE AREA (CM2)
1	5.5	.318	.0	1.950	.759	.452	2401.2	1066.8	.100	5.721
2	5.5	.318	.0	1.950	.759	.452	2439.9	914.4	.080	5.704
3	5.5	.330	.0	1.950	.759	.452	1235.3	868.7	1.400	***
4	5.5	.348	.0	1.950	.759	.452	957.7	457.2	1.780	2.180
5	5.5	.348	.0	1.950	.759	.452	1045.8	609.6	.690	2.613
6	5.5	.348	.0	1.950	.759	.452	1721.5	762.0	.210	3.878
7	5.5	1.270	.0	1.950	.759	.452	1961.7	260.3	***	***
8	5.5	2.540	.0	1.950	.759	.452	2536.9	553.2	***	***
9	5.5	.597	.0	3.890	1.013	.806	1468.8	762.0	.470	8.730
10	5.5	.635	.0	3.890	1.013	.806	799.5	365.8	1.280	10.435
11	5.5	.698	.0	3.890	1.013	.806	757.7	533.4	1.780	3.878
12	5.5	1.270	.0	3.890	1.013	.806	874.2	211.5	***	***
13	5.5	1.270	.0	3.890	1.013	.806	984.2	174.6	***	***
14	5.5	.318	.0	7.780	1.267	1.261	1810.5	1101.8	.840	15.518
15	5.5	.660	.0	7.780	1.267	1.261	719.9	367.0	***	***
16	5.5	.660	.0	7.780	1.267	1.261	732.7	373.1	***	***
17	5.5	.660	.0	7.780	1.267	1.261	1217.7	640.1	6.360	***
18	5.5	.660	.0	7.780	1.267	1.261	1236.3	701.0	***	***
19	5.5	1.270	.0	7.780	1.267	1.261	937.3	297.5	1.300	***
20	5.5	1.270	.0	7.780	1.267	1.261	1211.0	367.9	***	***
21	5.5	1.270	.0	7.780	1.267	1.261	1221.6	336.2	***	***
22	5.5	1.270	.0	7.780	1.267	1.261	1266.8	575.2	2.920	13.377
23	5.5	2.540	.0	7.780	1.267	1.261	1185.7	121.9	***	***
24	5.5	.330	.0	15.560	1.491	1.746	1199.1	1005.8	13.260	***
25	5.5	.635	.0	15.560	1.491	1.746	2603.8	1005.8	.340	26.320
26	5.5	1.270	.0	15.560	1.491	1.746	892.8	370.6	7.260	***
27	5.5	1.270	.0	15.560	1.491	1.746	597.3	377.3	7.130	***
28	5.5	1.270	.0	15.560	1.491	1.746	942.4	385.9	15.370	12.366
29	5.5	1.270	.0	15.560	1.491	1.746	1730.0	609.6	1.430	25.652
30	5.5	2.540	.0	15.560	1.491	1.746	937.6	196.6	11.220	***
31	5.5	2.540	.0	15.560	1.491	1.746	972.9	169.2	8.300	11.401
32	5.5	2.540	.0	15.560	1.491	1.746	1263.7	762.0	11.090	***
33	5.5	2.540	.0	15.560	1.491	1.746	1480.7	281.9	6.420	***
34	5.5	2.540	.0	15.560	1.491	1.746	1797.1	336.8	3.100	***

PENETRATION DATA

TARGET= TURALLOY DENSITY= 18.71 G/CC

NR	NOMINAL HARDNESS (KG/MM)	THICKNESS (CM)	OBLIQUITY (DEG)	PROJECTILE MASS (GRAMS)	PROJECTILE DIAMETER (CM)	PROJECTILE AREA (CM)	SPEED STRIKING (M/S)	SPEED RESIDUAL (M/S)	PRIMARY RESIDUAL MASS (GRAMS)	HOLE AREA (CM)
1	240.0	.254	.0	1.950	.759	.452	1090.6	434.9	1.490	.968
2	240.0	.254	.0	1.950	.759	.452	1446.6	548.6	1.040	***
3	240.0	.254	.0	1.950	.759	.452	2867.6	1371.6	.060	***
4	240.0	.318	.0	1.950	.759	.452	1734.9	487.7	.230	***
5	240.0	.381	.0	1.950	.759	.452	1618.8	457.2	.320	***
6	240.0	.508	.0	1.950	.759	.452	2840.4	762.0	.060	***
7	240.0	.254	.0	3.890	1.013	.806	925.7	320.9	.910	1.606
8	240.0	.254	.0	3.890	1.013	.806	1471.5	823.0	.320	***
9	240.0	.381	.0	3.890	1.013	.806	1484.7	414.5	.520	***
10	240.0	.508	.0	3.890	1.013	.806	1718.3	609.6	.130	***
11	240.0	.508	.0	3.890	1.013	.806	2535.3	792.5	.190	***
12	240.0	.254	.0	7.780	1.267	1.261	495.3	174.4	7.590	3.045
13	240.0	.254	.0	7.780	1.267	1.261	585.8	386.8	5.510	.832
14	240.0	.381	.0	7.780	1.267	1.261	1394.5	914.4	.190	***
15	240.0	.508	.0	7.780	1.267	1.261	1699.9	1219.2	.060	***
16	240.0	.508	.0	7.780	1.267	1.261	1843.4	962.3	.060	***
17	240.0	.254	.0	15.560	1.491	1.746	731.5	442.6	14.270	2.394
18	240.0	.318	.0	15.560	1.491	1.746	1418.2	762.0	14.590	***
19	240.0	.381	.0	15.560	1.491	1.746	1788.0	792.5	.260	***
20	240.0	.508	.0	15.560	1.491	1.746	1779.1	731.5	.780	***
21	240.0	.508	.0	15.560	1.491	1.746	1859.3	1219.2	.060	***
22	240.0	.508	.0	30.160	1.745	2.392	2171.4	540.1	1.360	8.548
23	240.0	.508	.0	30.350	1.745	2.392	1560.6	807.7	5.420	7.130

APPENDIX B

GRAPHIC COMPARISON OF THE THOR AND Z/F EQUATIONS

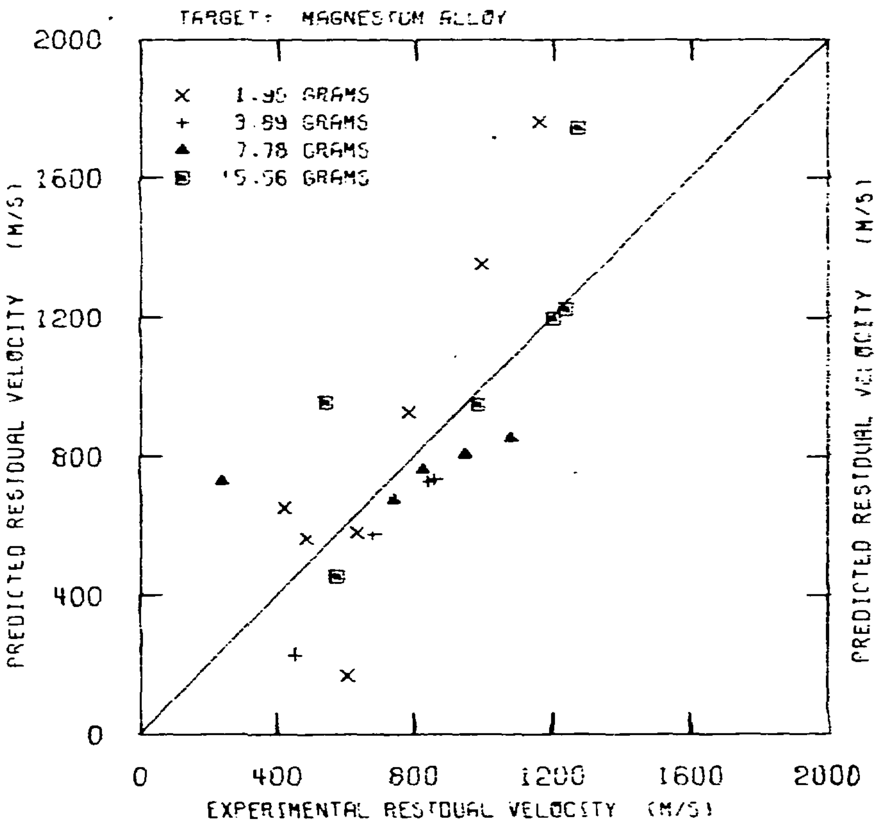


FIGURE THOR EQUATION

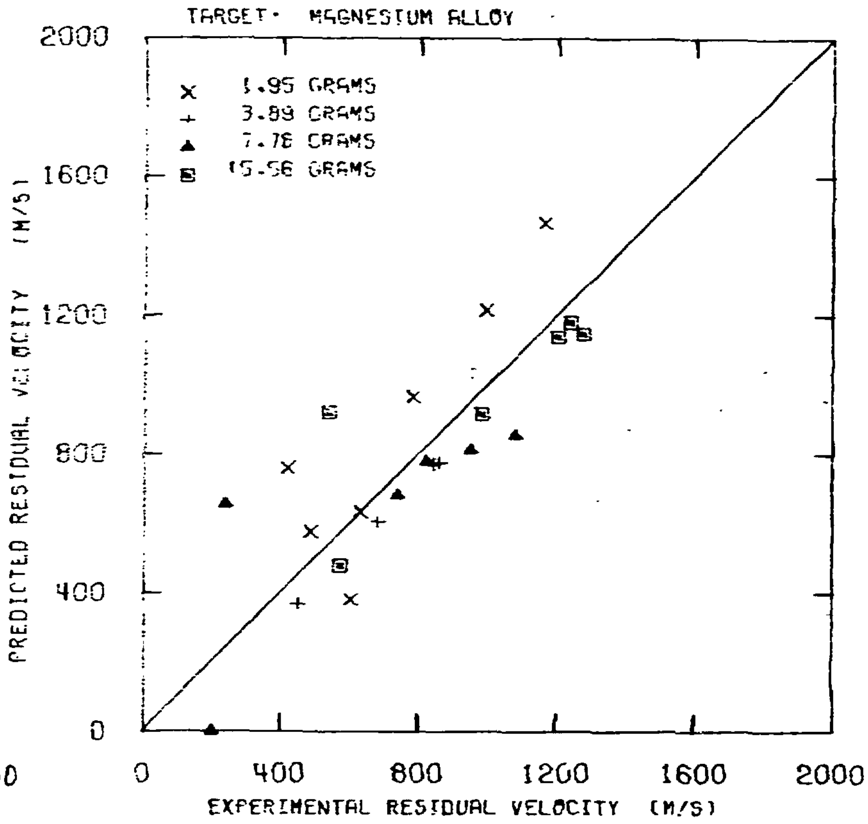


FIGURE Z/F EQUATION

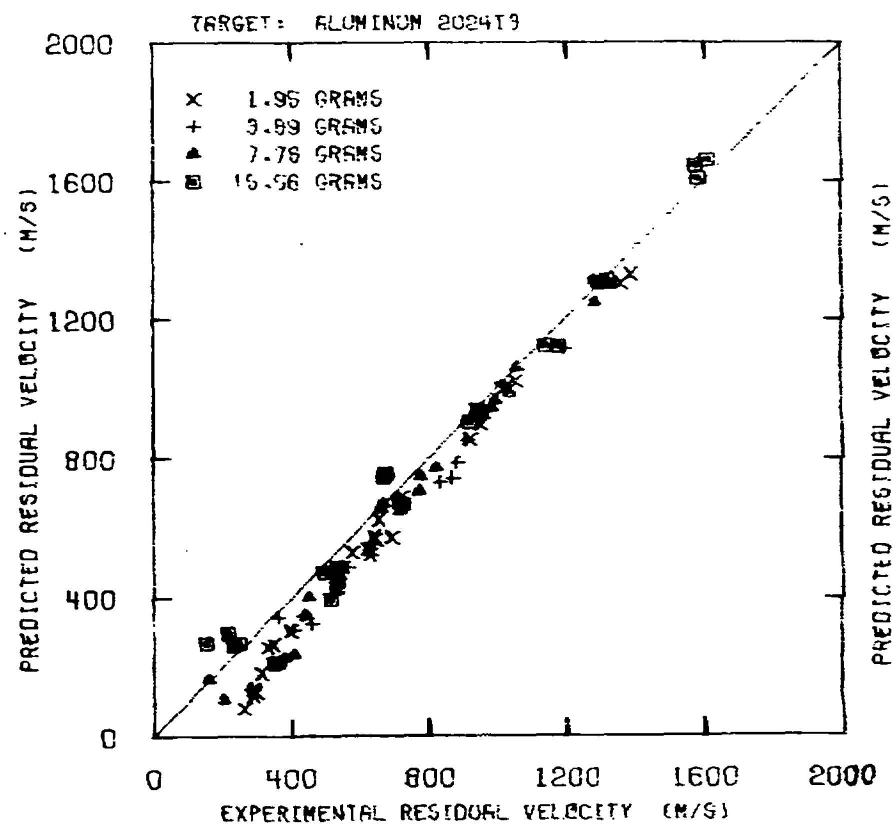


FIGURE THOR EQUATION

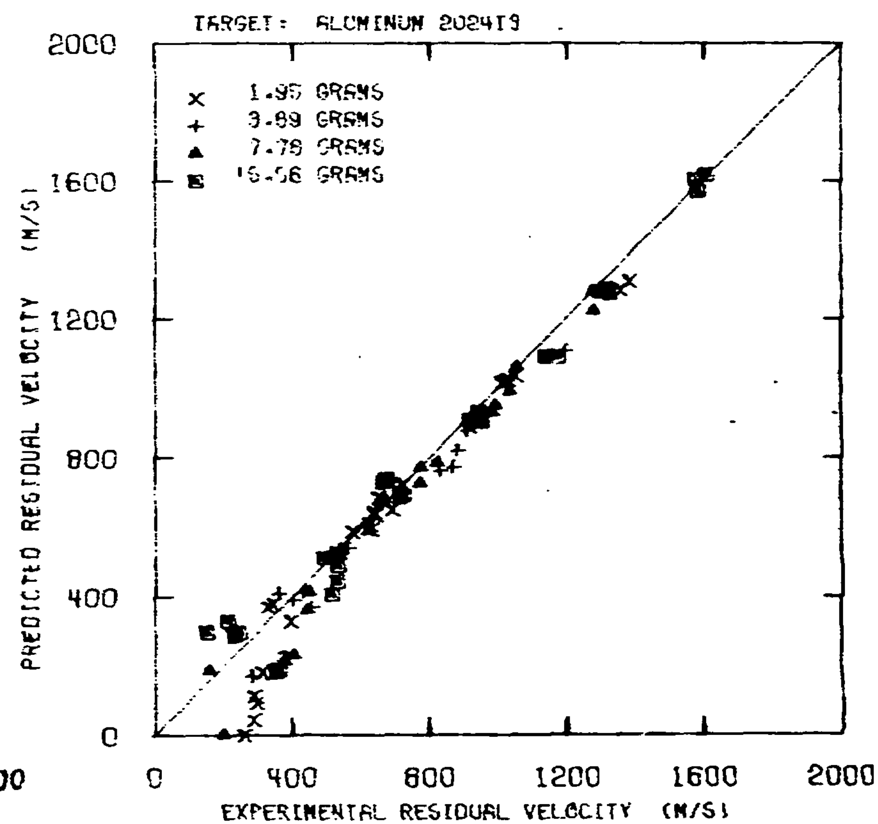


FIGURE Z/F EQUATION

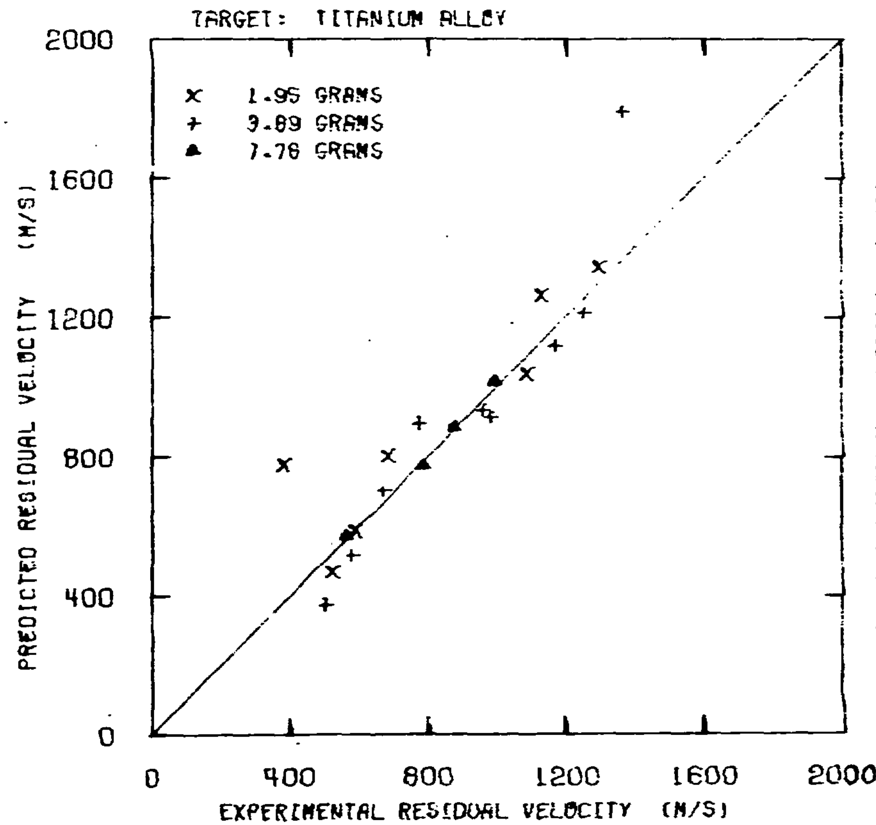


FIGURE THOR EQUATION

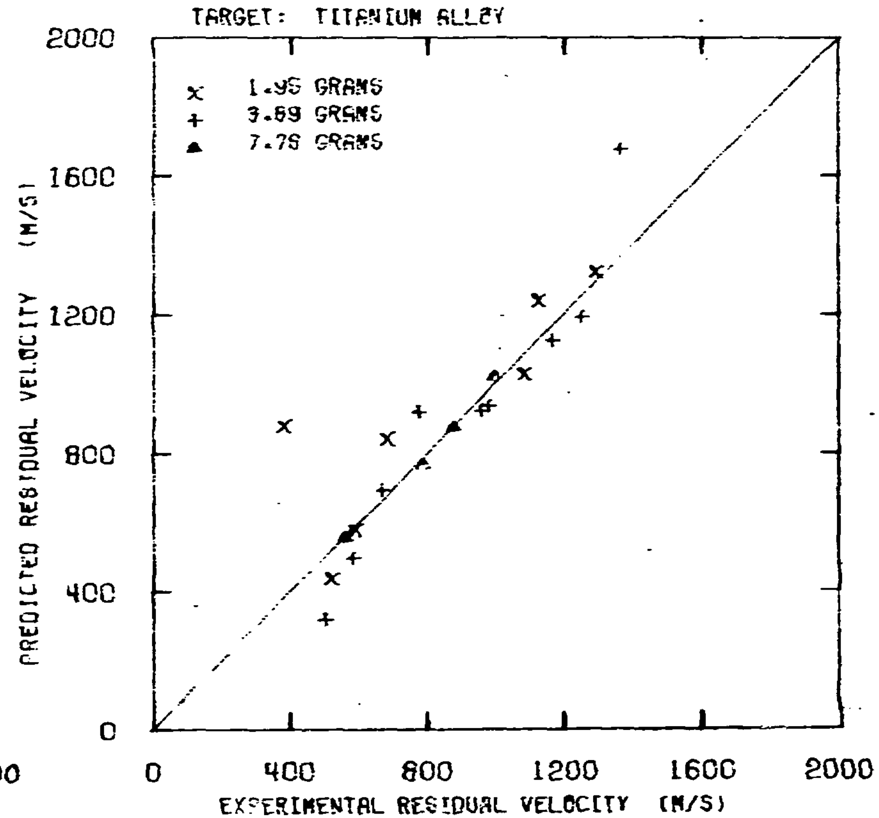


FIGURE Z/F EQUATION

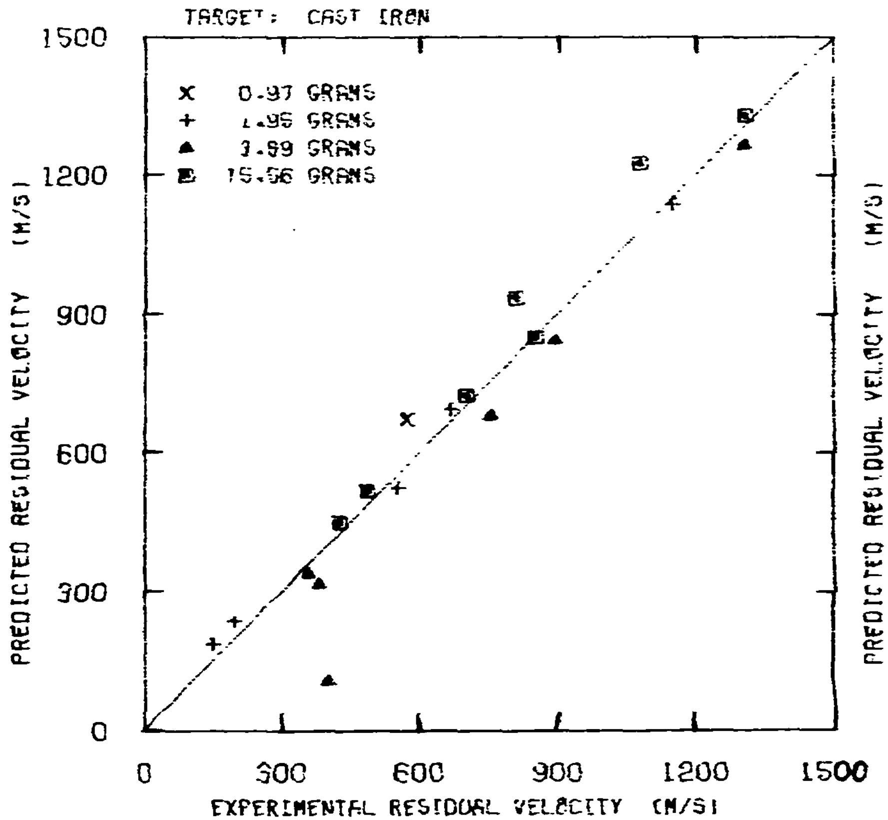


FIGURE THOR EQUATION

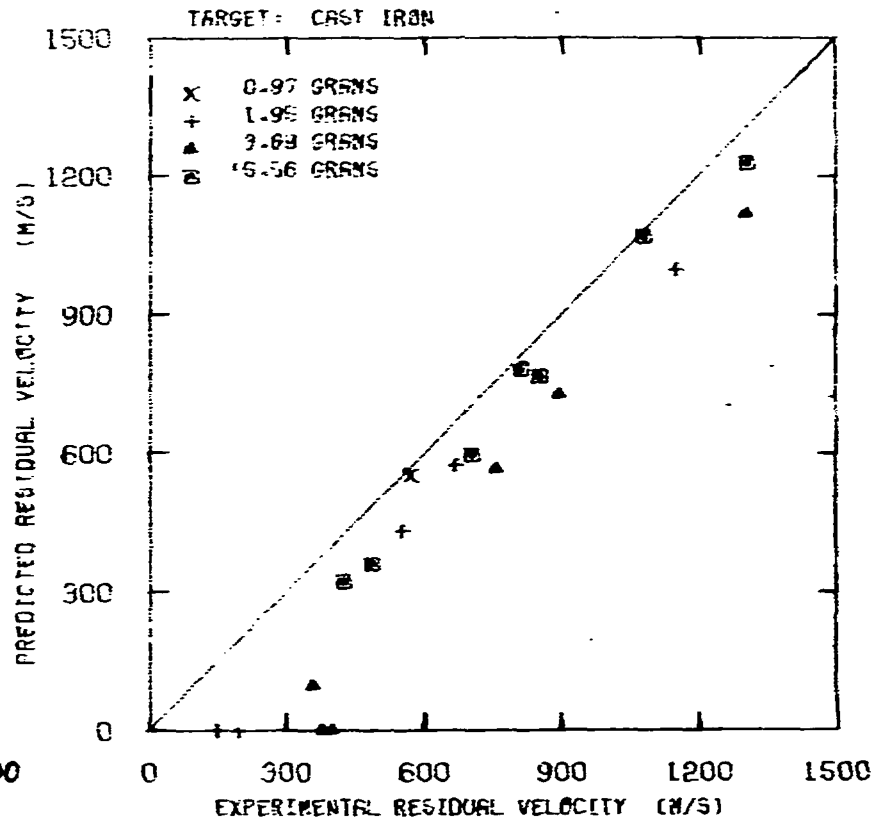


FIGURE Z/F EQUATION

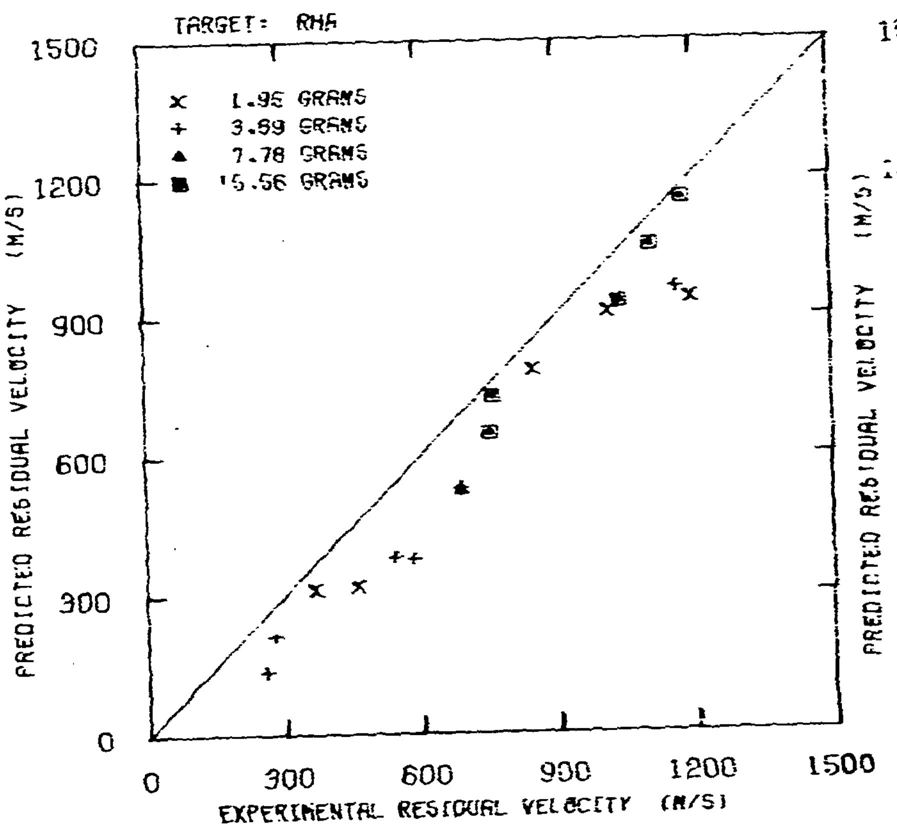


FIGURE THOR EQUATION

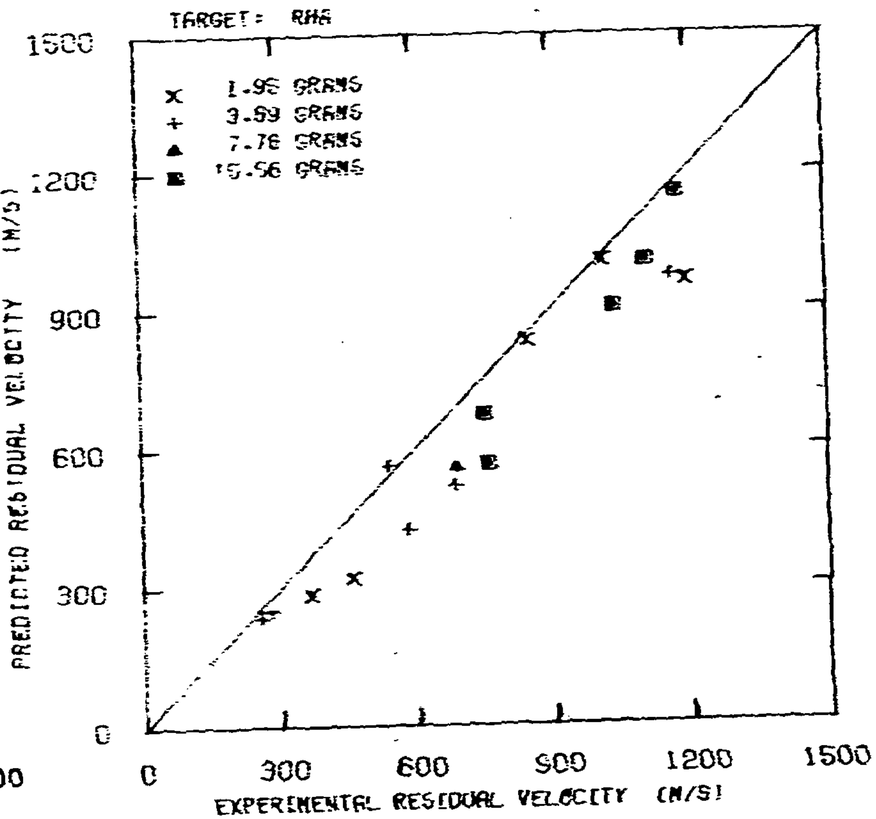


FIGURE Z/F EQUATION

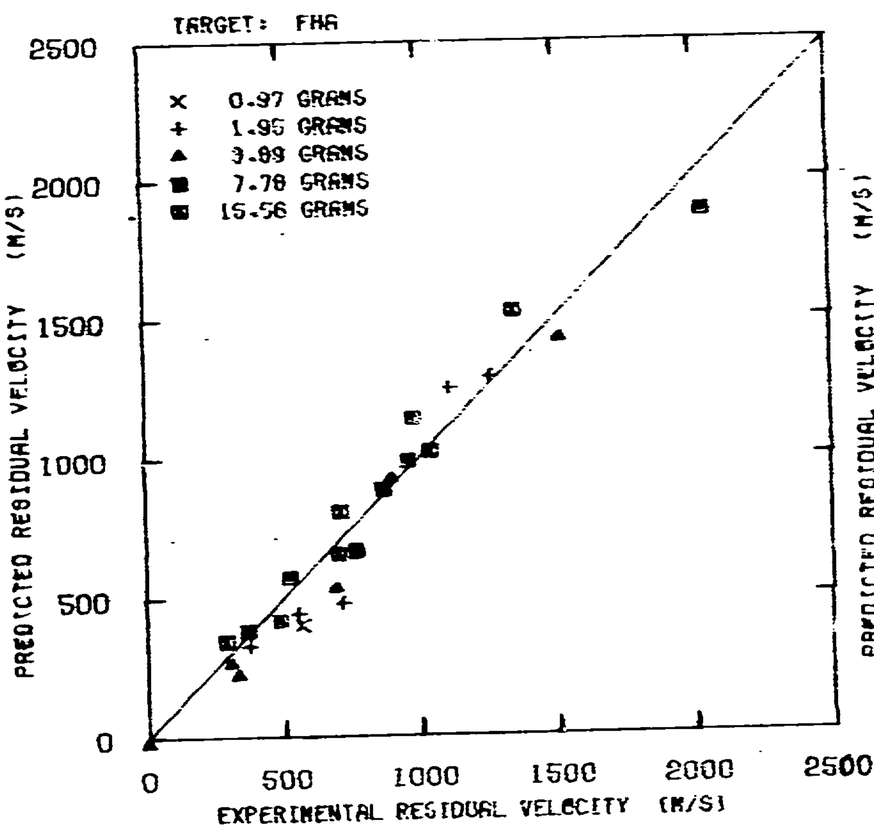


FIGURE THOR EQUATION

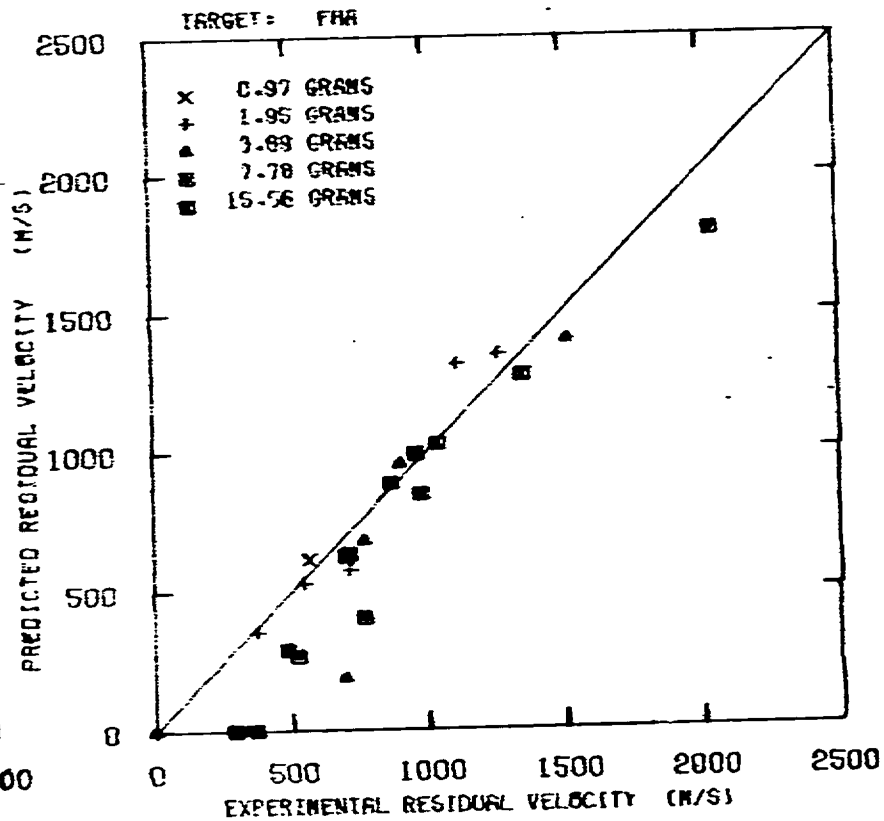
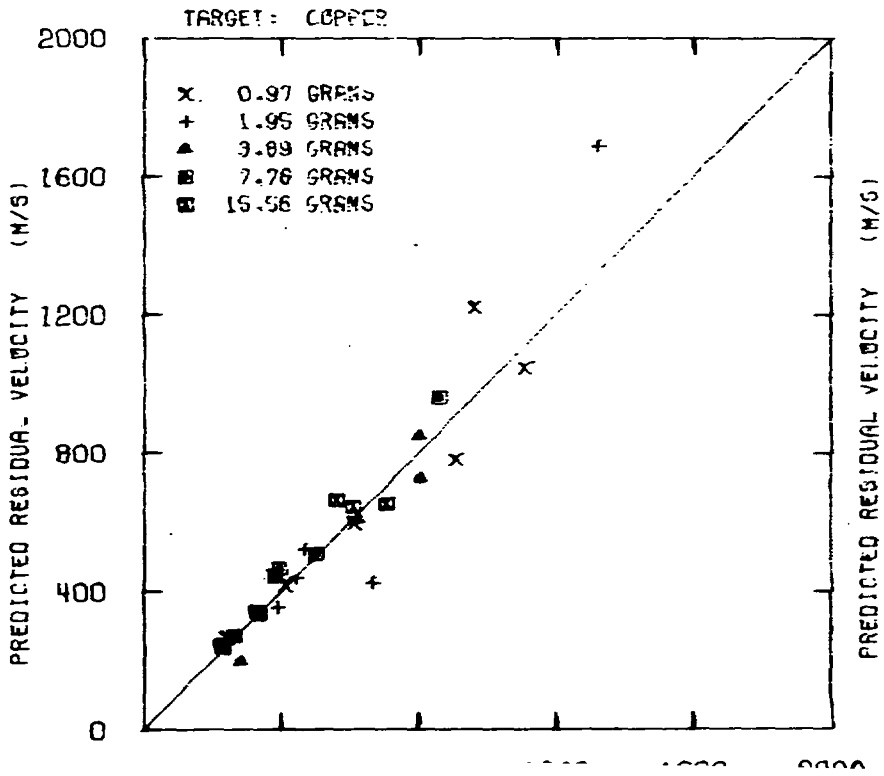
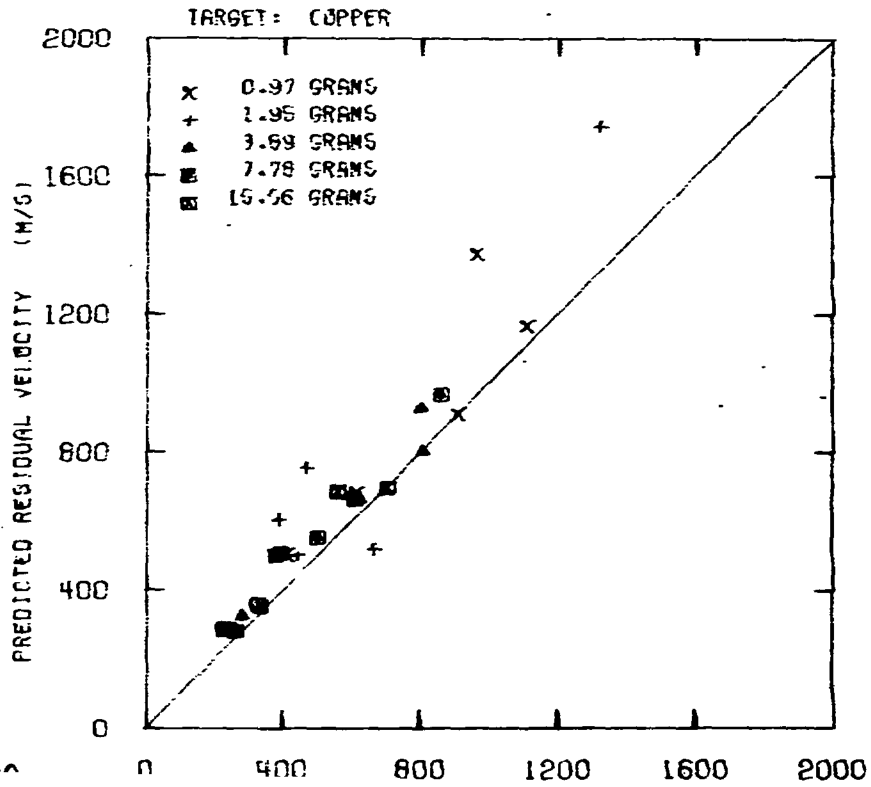


FIGURE Z/F EQUATION


TARGET: COPPER
X 0.97 GRAMS
+ 1.95 GRAMS
▲ 3.89 GRAMS
7.76 GRAMS
15.56 GRAMS
PREDICTED RESIDUAL VELOCITY (M/S)
2000
1600
1200
800
400
0


TARGET: COPPER
X 0.97 GRAMS
+ 1.95 GRAMS
▲ 3.89 GRAMS
7.78 GRAMS
15.56 GRAMS
PREDICTED RESIDUAL VELOCITY (M/S)
2000
1600
1200
800
400
0
0
400
800
1200
1600
2000

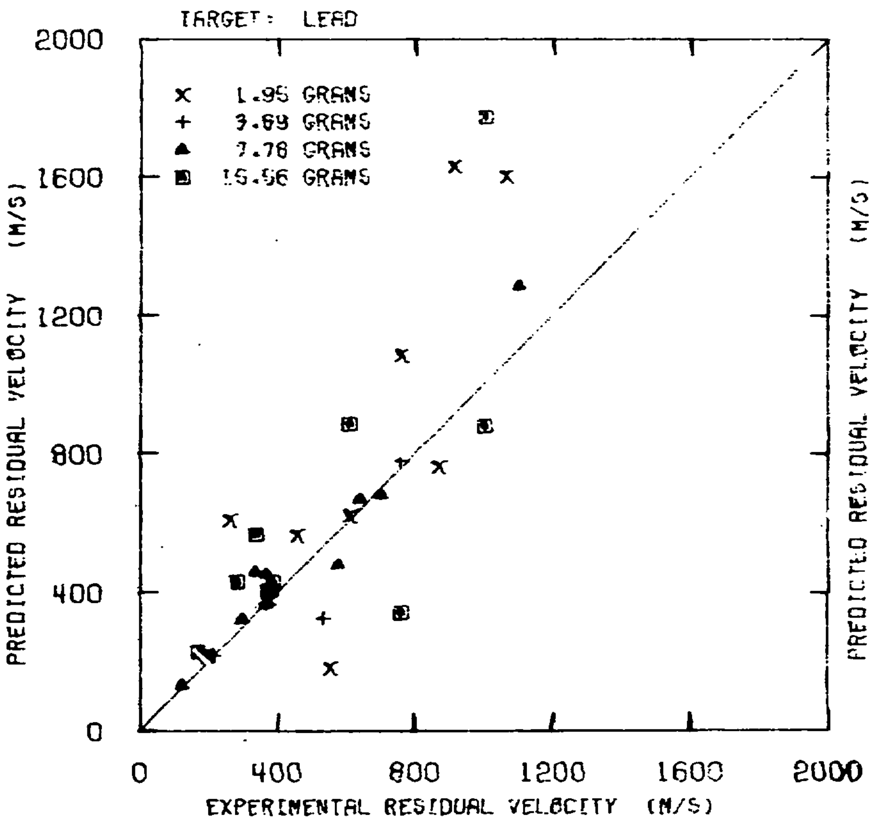


FIGURE THOR EQUATION

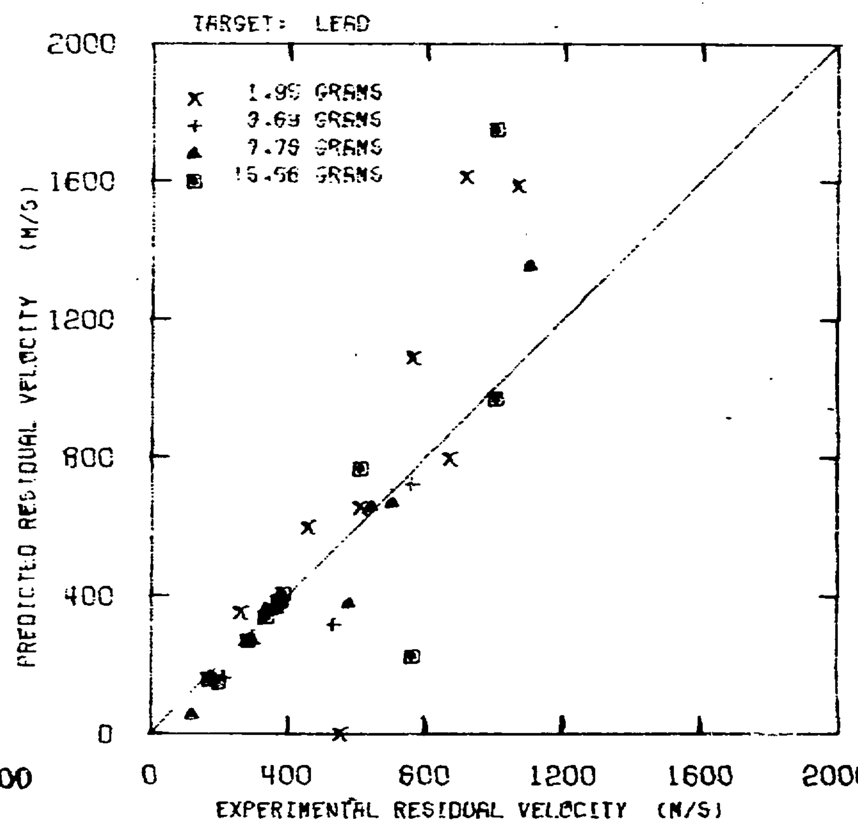


FIGURE Z/F EQUATION

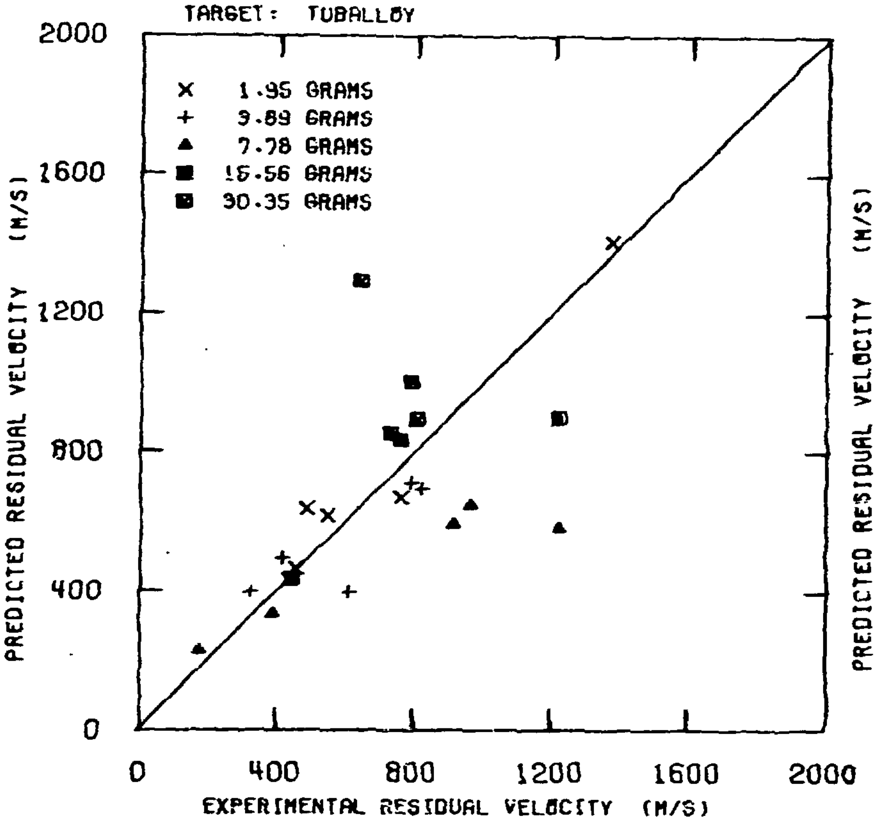


FIGURE THOR EQUATION

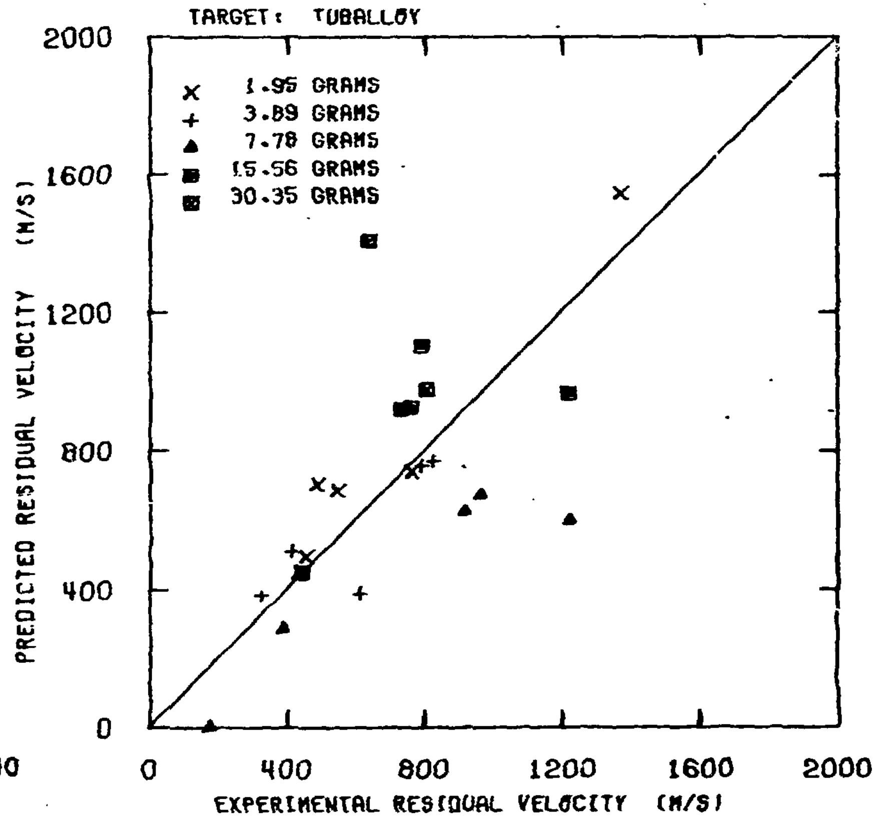


FIGURE Z/F EQUATION

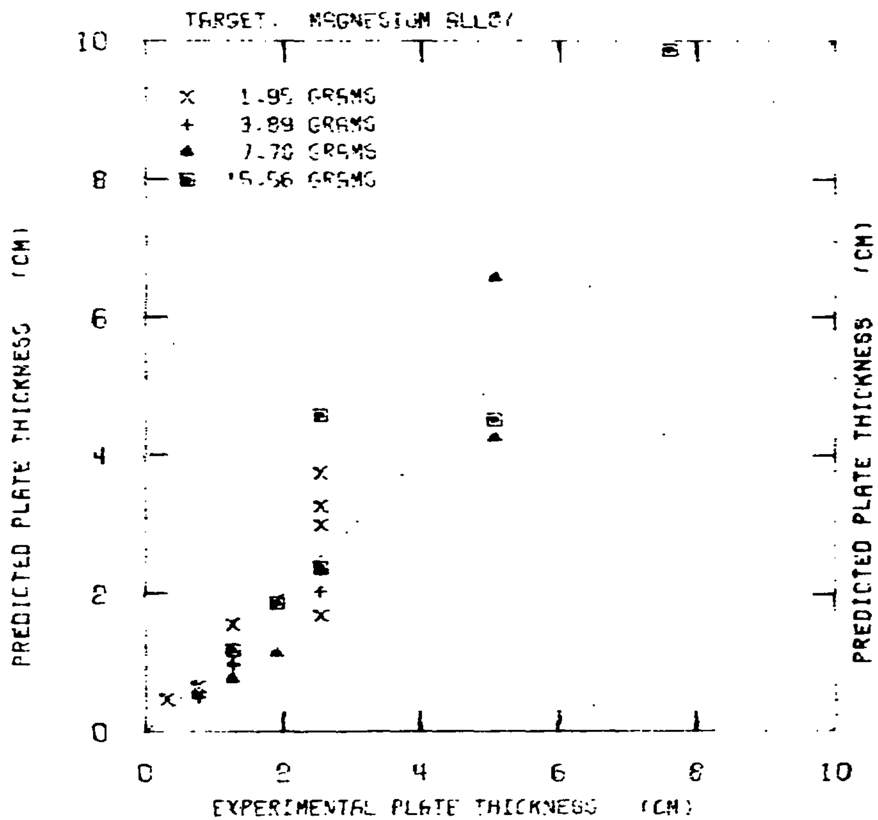


FIGURE THOR EQUATION

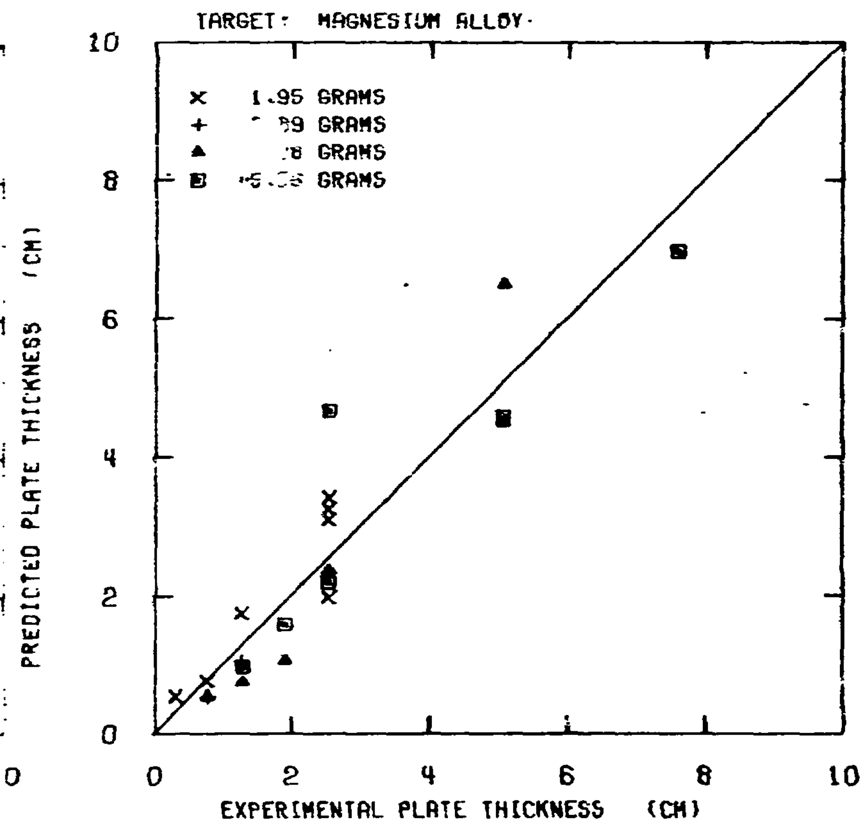


FIGURE Z/F EQUATION

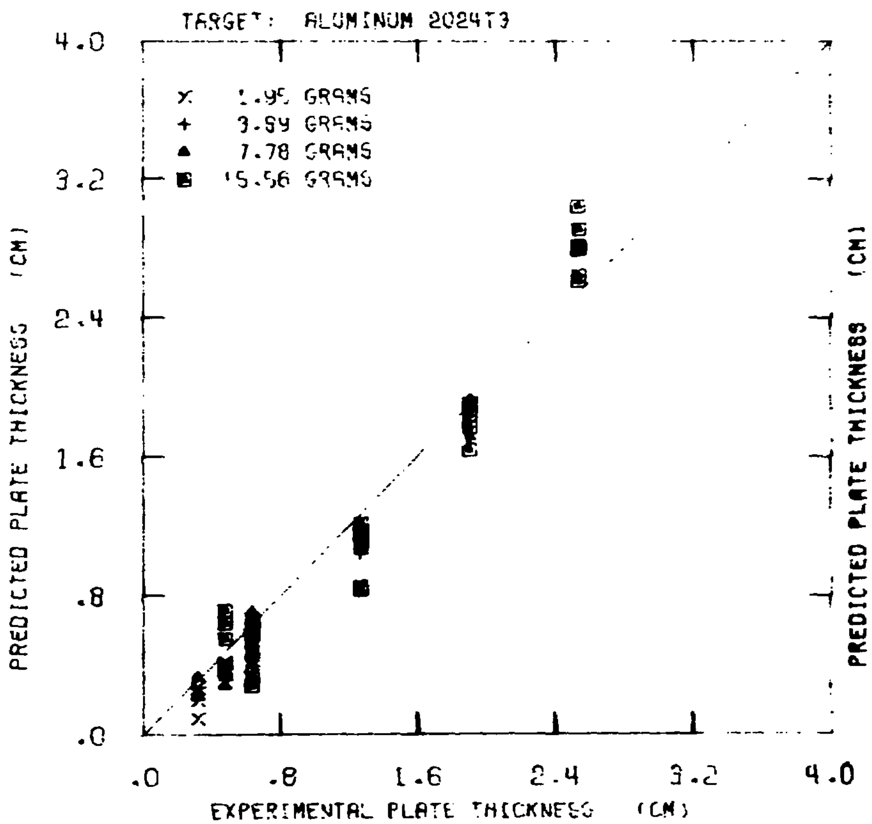


FIGURE THOR EQUATION

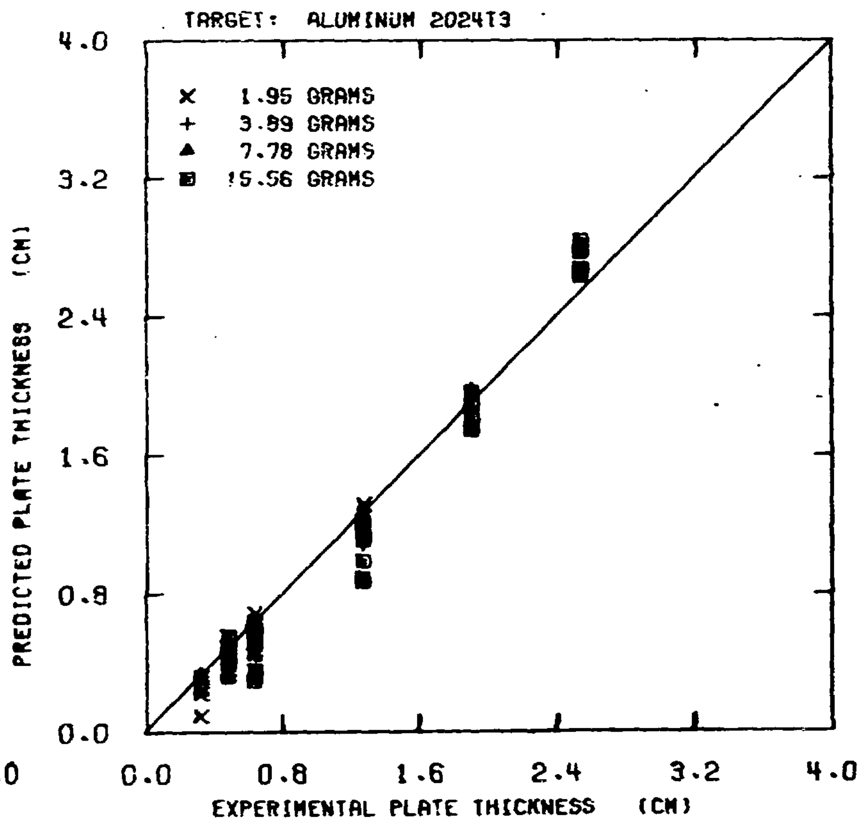


FIGURE Z/F EQUATION

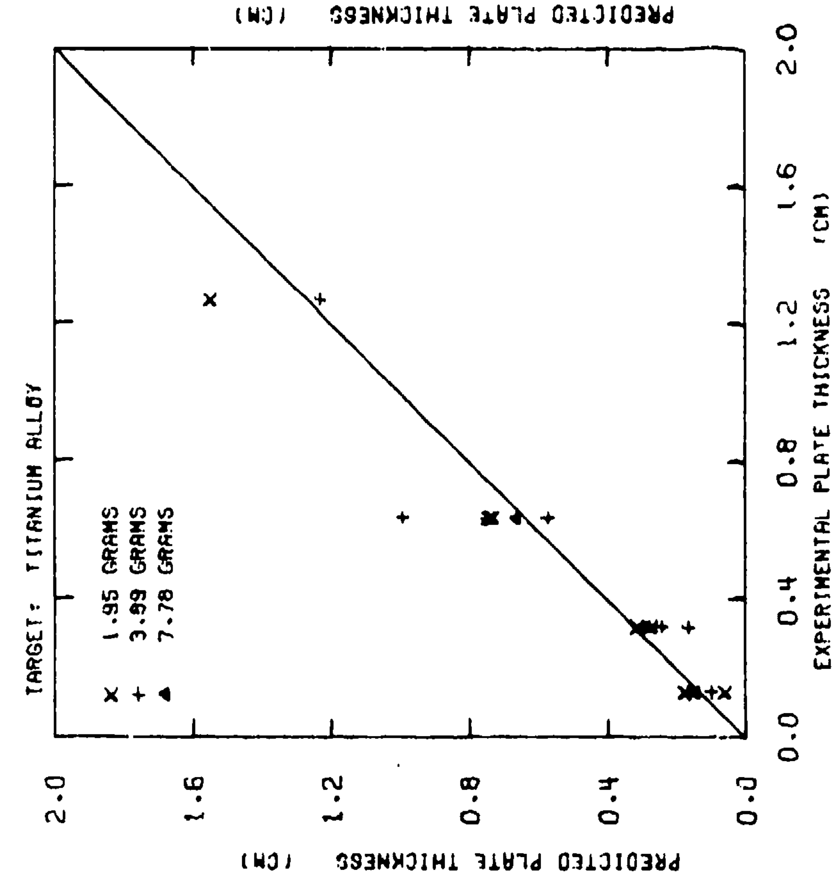


FIGURE THOR EQUATION

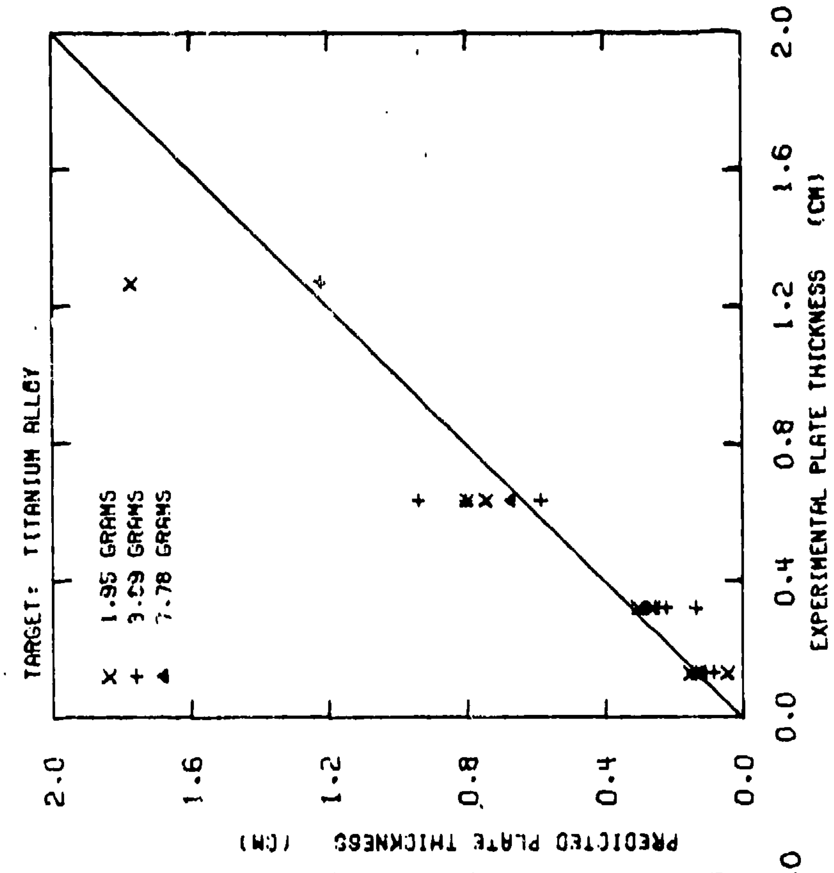


FIGURE Z/F EQUATION

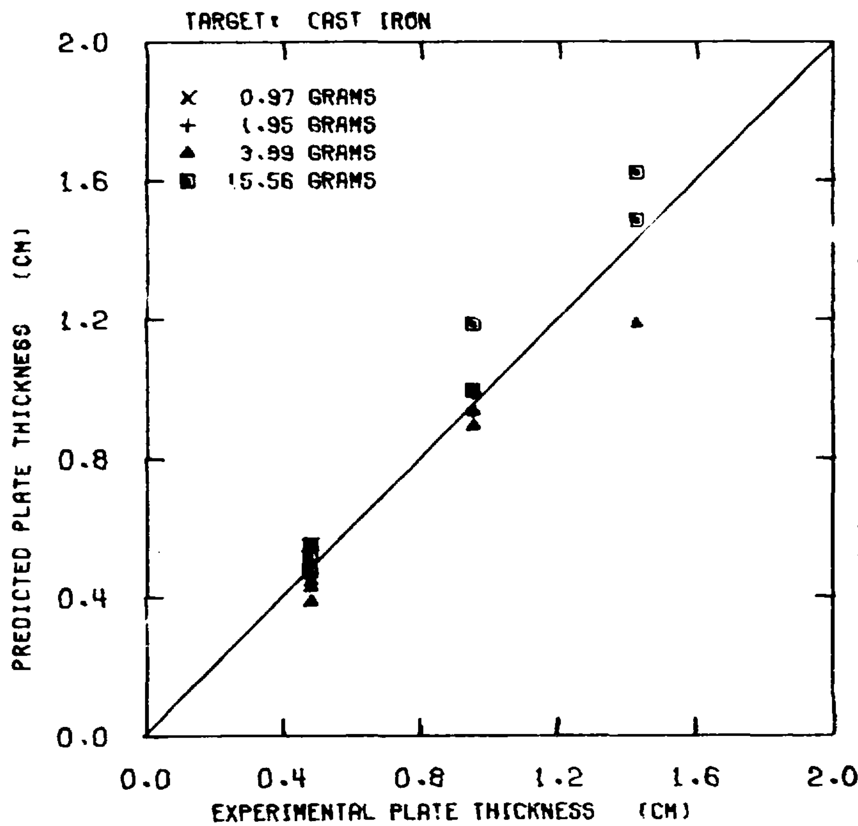


FIGURE THOR EQUATION

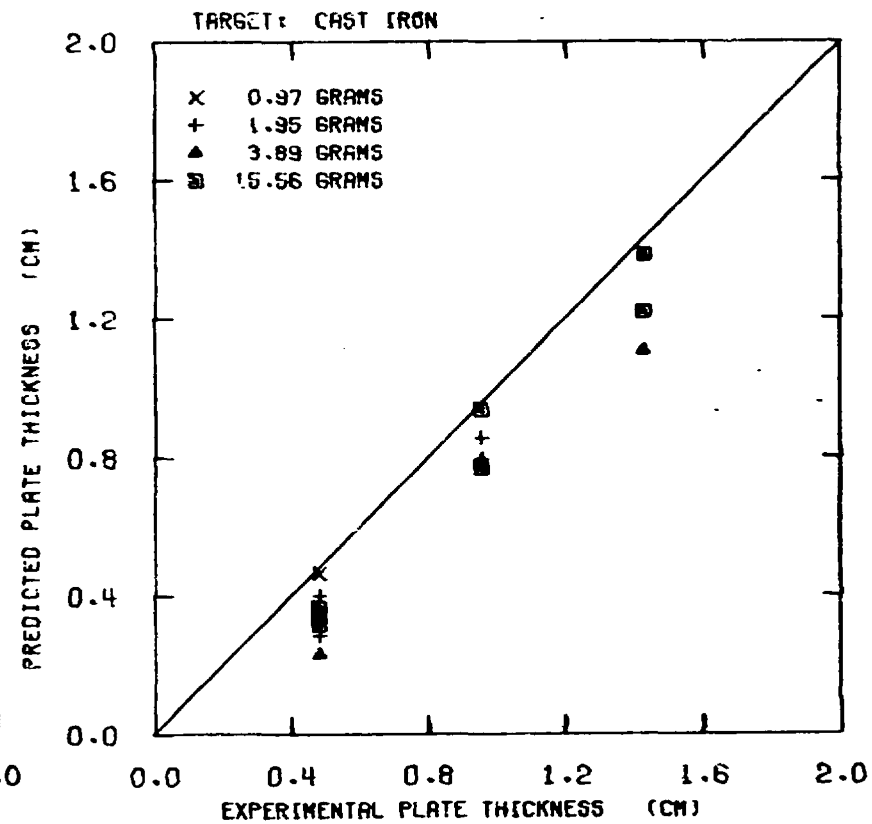


FIGURE Z/F EQUATION

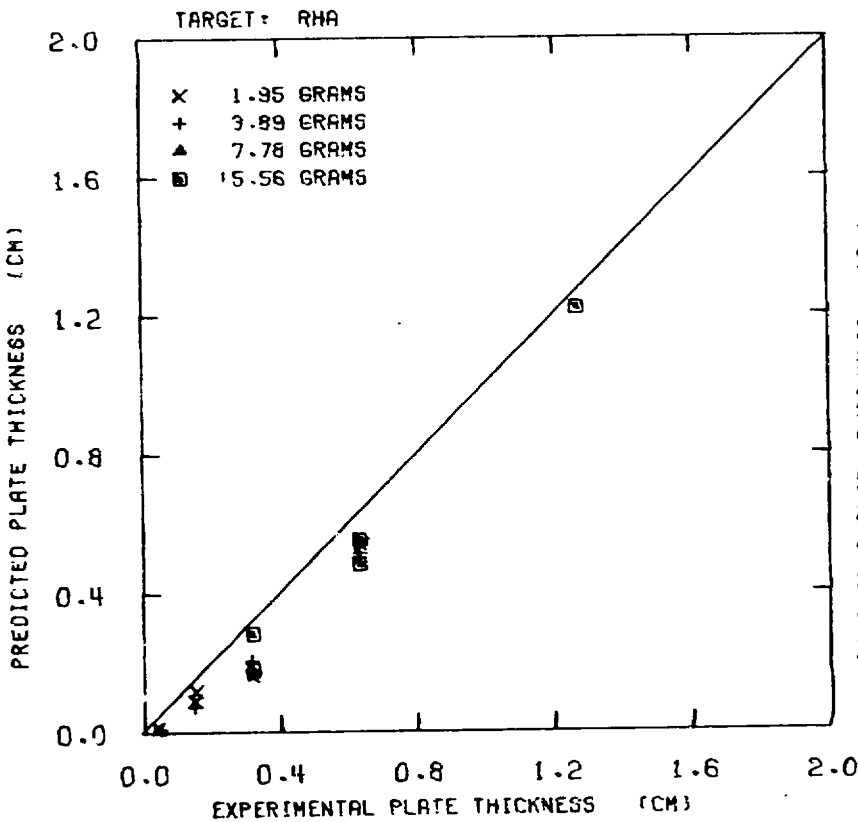


FIGURE THOR EQUATION

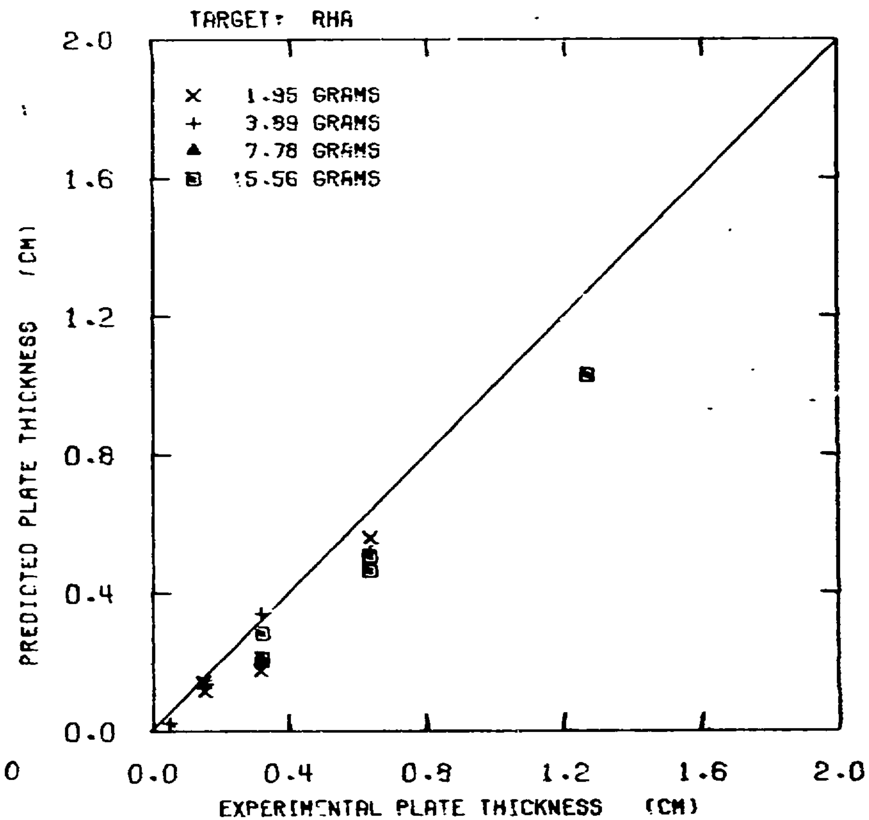


FIGURE Z/F EQUATION

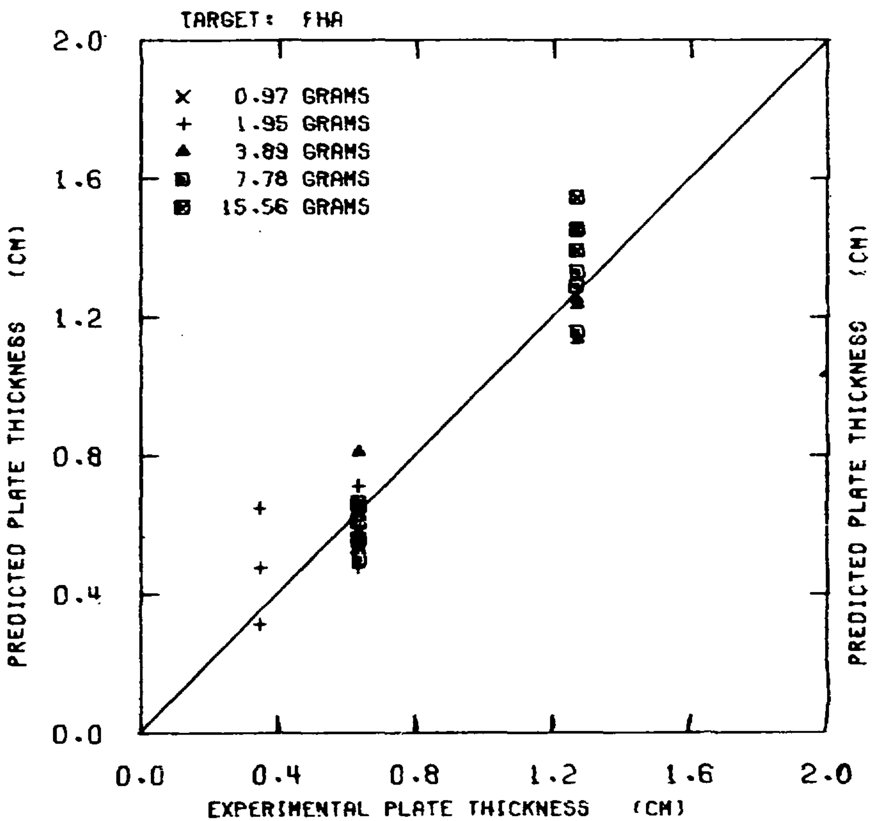


FIGURE THOR EQUATION

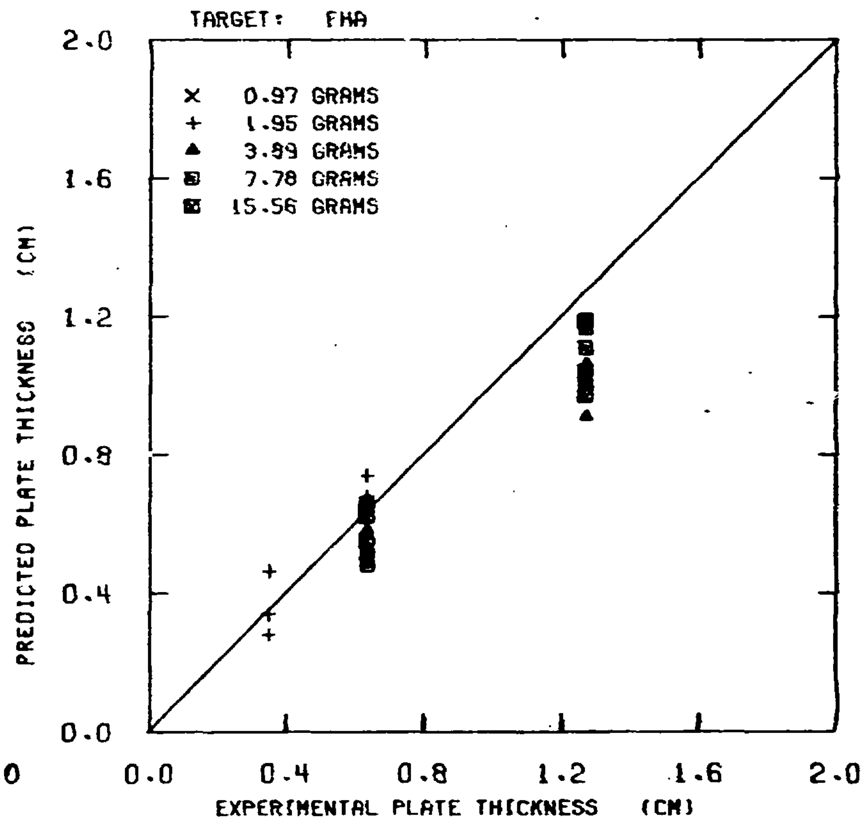


FIGURE Z/F EQUATION

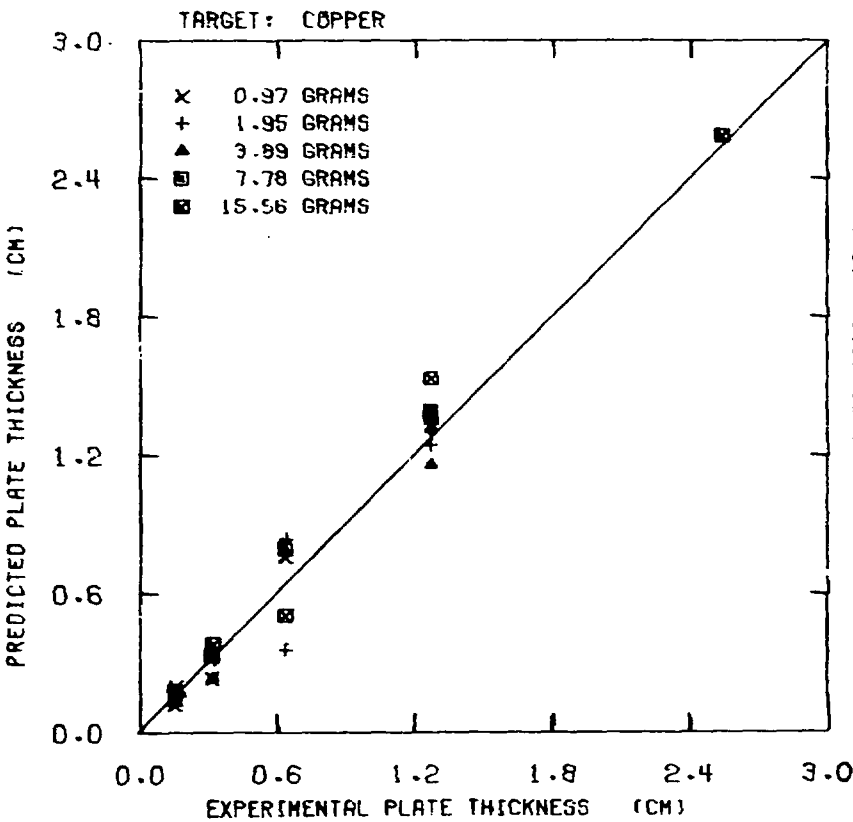


FIGURE THOR EQUATION

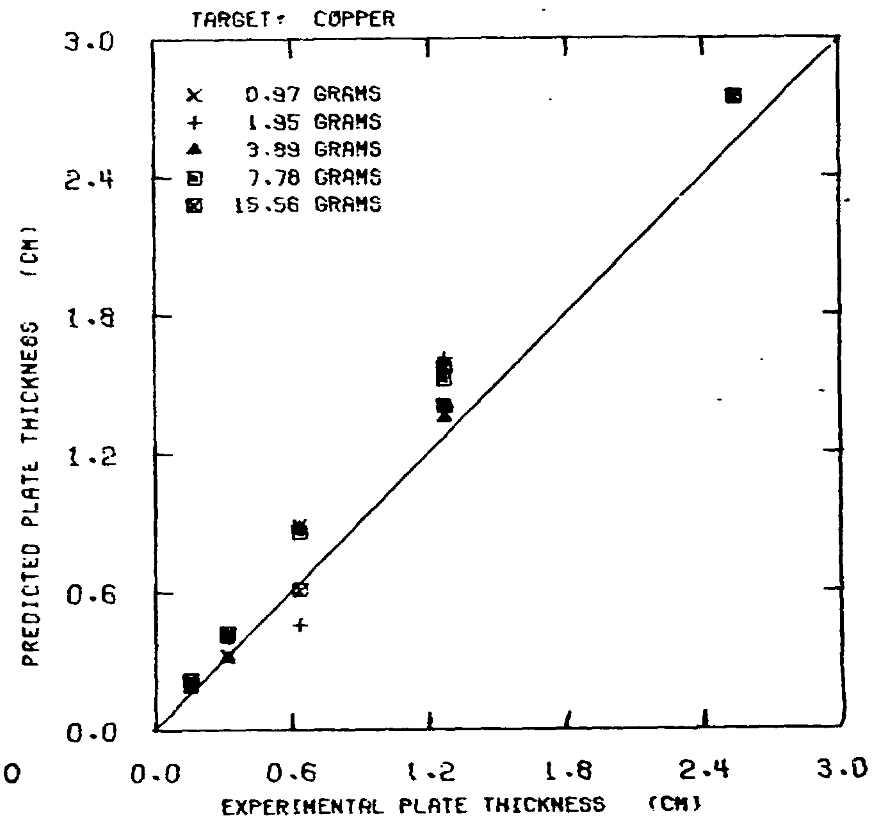


FIGURE Z/F EQUATION

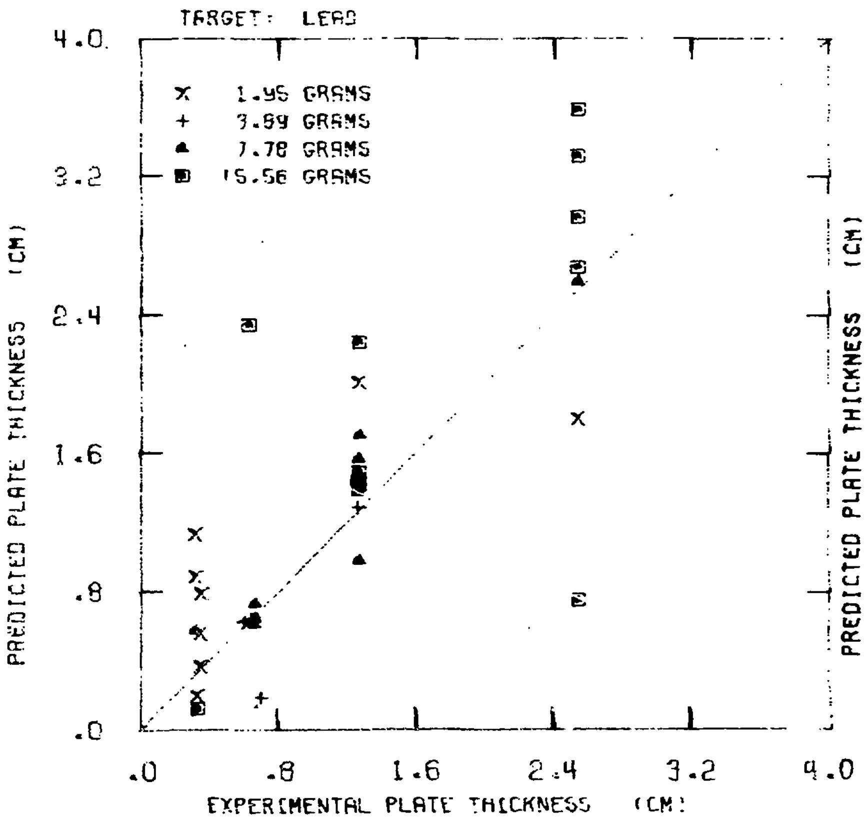


FIGURE THOR EQUATION

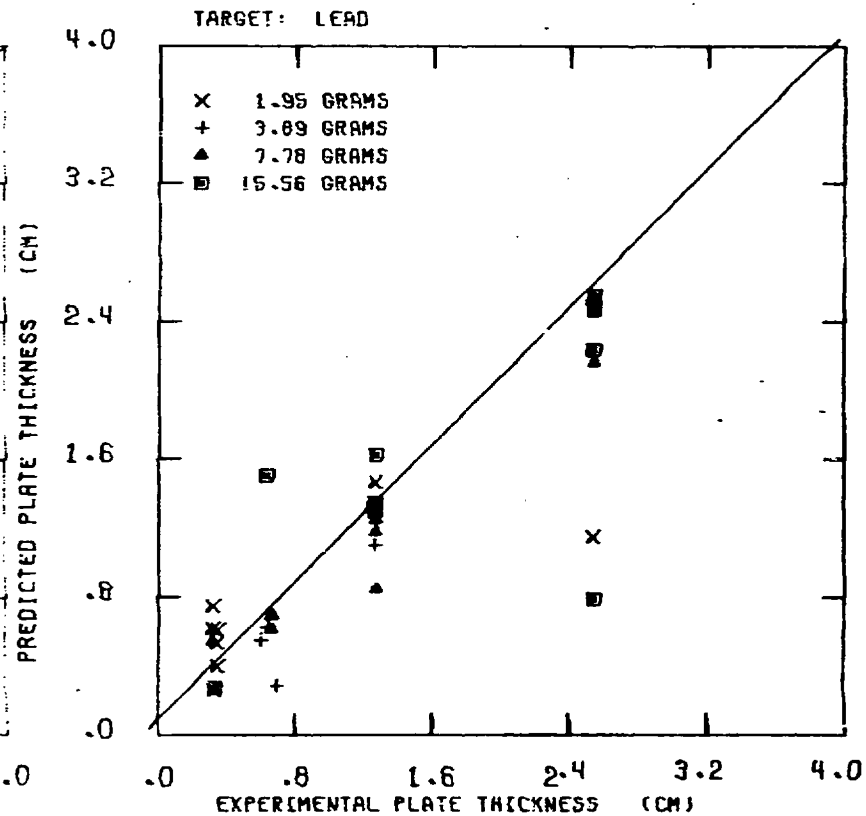


FIGURE Z/F EQUATION

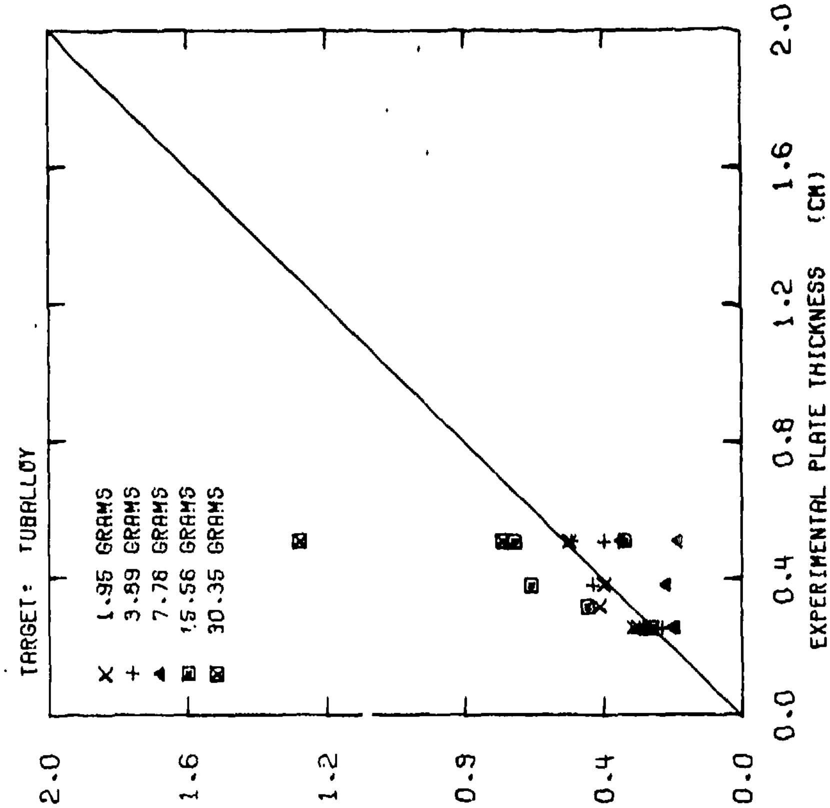


FIGURE Z/F EQUATION

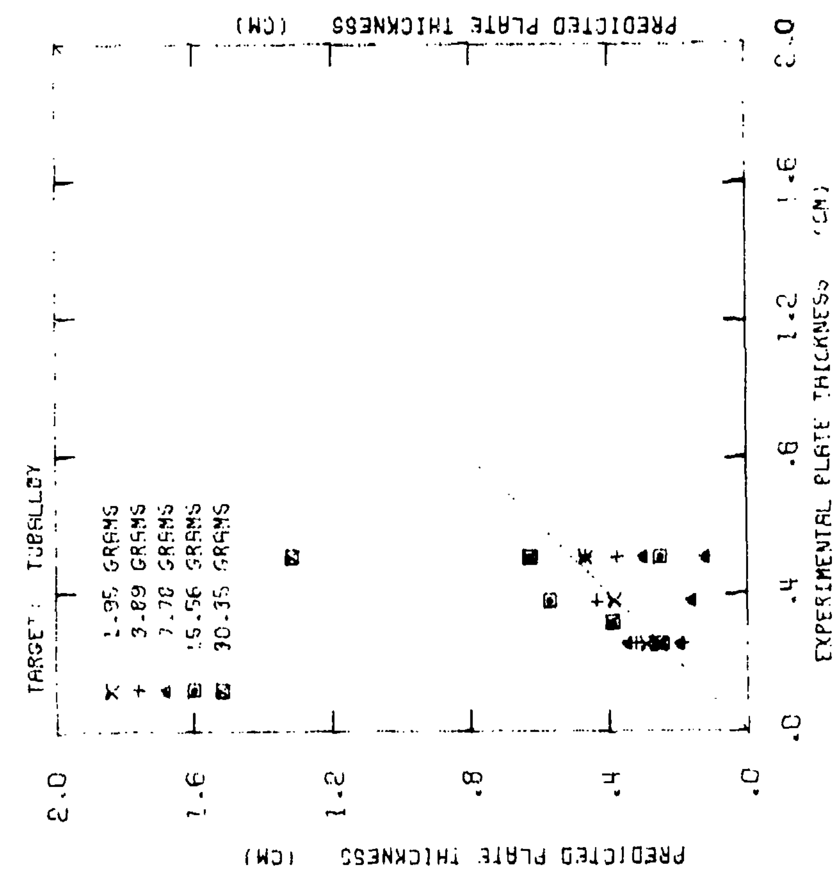


FIGURE THOR EQUATION

APPENDIX C

COMPUTER PROGRAM TABULATIONS AND SAMPLE OUTPUTS

```
C
C
C
C
C                               Z/F  FORCE PENETRATION MODEL
C
C
C                                       GLOSSARY
C
C   ***         IDENTIFIES REQUIRED INPUT DATA
C     *         IDENTIFIES INPUT DATA WHICH IS NOT REQUIRED
C
C
C
C          A         - FIRST TERM OF THE FORCE EQUATION  (K1)
C          AA        - STATIC FORCE COMPONENT  (DYNES)
C   ***    ANG       - IMPACT ANGLE  (DEGREES)
C          AMF       - CONSTANT BASED ON LEAST SQUARE FIT TO DATA
C          B         - COEFFICIENT OF SECOND TERM OF THE FORCE EQUATION  (K2)
C          BMF       - CONSTANT BASED ON LEAST SQUARE FIT TO DATA
C          C         - COEFFICIENT OF THIRD TERM OF THE FORCE EQUATION  (K3)
C          CMF       - CONSTANT BASED ON LEAST SQUARE FIT TO DATA
C          DELT      - DELTA TIME INCREMENT
C          DELTAV    - DELTA SPEED DECREMENT
C          DELV      - COMPUTED DROP IN SPEED BASED ON VR1 AND F1
C          DELVP     - COMPUTED DROP IN SPEED BASED ON VR2 AND F2
C          DELX      - X INCREMENTAL VALUE
C          DEVANT    - THE COMPUTED RESIDUAL VELOCITY MINUS THE EXPERIMENTAL
C                        RESIDUAL VELOCITY  ( THE DEVIANT )
C          F1        - FORCE ACTING AT START OF X INCREMENT
C          F2        - FORCE ACTING AT END OF X INCREMENT
C          FORCE     - TOTAL FORCE
C          FV1       - COMPONENT OF FORCE PROPORTIONAL TO SPEED
C          FV2       - COMPONENT OF FORCE PROPORTIONAL TO SPEED SQUARED
C     *    HDIA      - HOLE DIAMETER  (CM)
C          ICNT      - INDEX COUNTER
C     *    IR        - SHOT IDENTIFICATION NUMBER
C          PCA       - PROJECTILE CROSS-SECTIONAL AREA  (SQ CM)
C   ***    PDIA      - PROJECTILE DIAMETER  (CM)
C   ***    PMASS     - PROJECTILE MASS  (GRAMS)
C          PRESUR    - STATIC PRESSURE ACTING ON PROJECTILE  (MEGA-PASCALS)
C          RATIO     - THE COMPUTED RELATIVE ERROR
C     *    RMASS     - PRIMARY RESIDUAL FRAGMENT MASS  (GRAMS)
C          SUMFT     - TOTAL IMPULSE TO DEPTH X (DYNE-SECS)
C   ***    TBHN      - TARGET PLATE BRINELL HARDNESS NUMBER  (KG/MM**2)
C          TEST      - VALUE TO BE TESTED
C   ***    THICK     - TARGET PLATE THICKNESS  (CM)
```

```
C           TIME       - PENETRATION TIME  (MICRO SECONDS)
C    ***    TRHO       - TARGET PLATE DENSITY  (G/CC)
C           VR         - RESIDUAL SPEED  (CM/SEC)
C           VR1        - RESIDUAL SPEED AT START OF X INCREMENT
C           VR2        - RESIDUAL SPEED AT END OF X INCREMENT
C      *    VRE        - EXPERIMENTAL RESIDUAL SPEED  (M/S)
C           VRP        - RESIDUAL SPEED  (M/S)
C           VS         - STRIKING SPEED (CM/S)
C    ***    VSP        - STRIKING SPEED (M/S)
C           X          - DEPTH OF PENETRATION (CM)
C           XPRT       - DETERMINES WHEN TO PRINT OUTPUT
C           XPRTI      - THE PRINT INCREMENTAL VALUE
C
C
C
      DATA PI/3.141592654/
      AMF=0.70
      BMF=0.23
      CMF=0.50
      WRITE(6,60)
   60 FORMAT(1H1/1H0,20X,40HSAMPLE OUTPUT FOR  Z/F FORCE PENETRATION ,
     1    35H MODEL PREDICTING RESIDUAL VELOCITY  /)
   90 CONTINUE
C         READ CARD WHICH IDENTIFIES TARGET MATERIAL
      READ(5,95)TGT1,TGT2,TGT3
      WRITE(6,95)TGT1,TGT2,TGT3
   95 FORMAT(3A6)
      ICNT=0
  100 CONTINUE
C         A BLANK CARD SEPARATES TARGET MATERIAL GROUPS
C         END PUNCHED IN COLUMNS 1 TO 3 WILL TERMINATE THE PROGRAM
      READ(5,110)NR,TRHO,TBHN,THICK,ANG,PMASS,PDIA,VSP,VRE,RMASS,HDIA
  110 FORMAT(A6,F6.2,F6.1,F8.3,F5.1,F6.2,F6.3,2F8.1,2F7.2)
      IF(TBHN.LE.0.0)GOTO 900
C        CONVERT STRIKING SPEED TO  CM/SEC
      VS=VSP*100.0
C        COMPUTE CROSS-SECTIONAL AREA
      PCA=PI*(PDIA/2.0)**2
C        COMPUTE K1, K2 AND K3  ( = A,B,C)
      A=9.8E7*TBHN
      B=SQRT(A*TRHO)*BMF
      C=TRHO*CMF
      A=A*AMF
      AA=PCA*A
      VR=VS
C         DETERMINE PRINT FREQUENCY AND INITIAL DELTA X INCREMENT
      XPRTI=THICK/10.0
```

```
      DELX=THICK/10.0
      IF(DELX .GT. 0.01) DELX=0.01
C        INITIALIZE VARIABLES
      X=0.0
      XPRT=0.0
      TIME=0.0
      SUMFT=0.0
      ICNT=ICNT+1
      WRITE(6,115)ICNT ,NR
  115 FORMAT(1H0/1H0,50X,13HDATUM SET NR.,I5,10X,12HIDENTIFIER =,2X,A6/)
      WRITE(6,150)
  150 FORMAT(1H0,9X,1HX,8X,2HVR,10X,5HF(V0),10X,5HF(V1),10X,5HF(V2),10X,
     1   5HFORCE,8X,4HTIME,4X,8HPRESSURE,5X,7HIMPULSE   )
      WRITE(6,151)
  151  FORMAT(1H ,6X,4H(CM),5X,5H(M/S),8X,7H(DYNES),8X,7H(DYNES),8X,
     1   7H(DYNES),8X,7H(DYNES),4X,8H(MU-SEC),6X,18H(M PA)  (DYNE-SEC)/)
C        COMPUTE FORCE AND STATIC PRESSURE ACTING AT X=0 BASED ON VR=VS
      FV1=PCA*B*VS
      FV2=PCA*C*VS**2
      FORCE=AA+FV1+FV2
      PRESUR=FORCE/PCA*1.E-7
      WRITE(6,251)X,VSP,AA,FV1,FV2,FORCE,TIME,PRESUR,SUMFT
  200 CONTINUE
      IF(X .GE. THICK) GOTO 300
      IF(VR.LT.10.0)GOTO 290
C         THE FOLLOWING STATEMENT INSURES THAT THE PLATE THICKNESS
C         WILL NOT BE EXCEEDED
      IF((X+DELX) .GT. THICK) DELX=THICK-X
      IF(DELX .LE. 0.0) GOTO 300
C        COMPUTE FORCE ACTING AT X1 BASED ON V1
      VR1=VR
      F1=PCA*(A+B*VR1+C*VR1**2)
  220 CONTINUE
C        COMPUTE DELTA V' BASED ON F1
      DELV=F1*DELX/(PMASS*VR1)
      VR2=VR-DELV
      IF(VR2.LT.0.0)GOTO 290
C        COMPUTE FORCE F2 ACTING AT X2 BASED ON  V2=V1-DELV'
      F2=PCA*(A+B*VR2+C*VR2**2)
C        COMPUTE DELTA V'' BASED ON F2
      DELVP=F2*DELX/(PMASS*VR2)
C        MAKE TEST
      TEST=(DELV-DELVP)/ ((DELV+DELVP)/2.0)
      IF(ABS(TEST).LT.0.001)GOTO 250
      IF(DELX.LT.1.E-5)GOTO 250
C        FAILS TEST - REDUCE DELX BY HALF  (MINIMUM IS 0.00001 CM. )
      DELX=DELX/2.0
```

```
      GOTO 220
  250 CONTINUE
  251 FORMAT(1H ,F10.3,F10.1,1P4E15.5,0PF12.3,2F12.1)
C        MEETS TEST
      DELTAV=(DELV+DELVP)/2.0
C        COMPUTE VR=V1-DELTA V
      VR=VR-DELTAV
C        FIND THE AVERAGE FORCE ACTING OVER THE INTERVAL
      FORCE=(F1+F2)/2.0
C        UPDATE THE DEPTH OF PENETRATION X
      X=X+DELX
C        UPDATE THE PENETRATION TIME IN MICRO-SECONDS
      DELT=PMASS*DELTAV/FORCE*1.E6
      TIME=TIME+DELT
C        UPDATE THE TOTAL IMPULSE EXPERIENCED BY THE PROJECTILE
      SUMFT=SUMFT+FORCE*DELT *1.E-6
C        CHECK FOR PRINTING INFORMATION
      IF(X.GE.XPRT)GOTO 260
      GOTO 200
  260 CONTINUE
C        RESOLVE THE VARIABLE COMPONENTS OF THE FORCE
      FV1=PCA*B*(VR+DELTAV/2.0)
      FV2=PCA*C*(VR+DELTAV/2.0)**2
C        COMPUTE THE STATIC PRESSURE
      PRESUR=FORCE/PCA*1.E-7
      VRP=VR/100.0
      WRITE(6,251)X,VRP,AA,FV1,FV2,FORCE,TIME,PRESUR,SUMFT
      XPRT=XPRT+XPRTI
C        CONTINUE CYCLING UNTIL TARGET PLATE IS COMPLETELY PENETRATED
C        OR UNTIL THE RESIDUAL SPEED IS LESS THAN 10 CM/SEC.
      GOTO 200
  290 CONTINUE
C        DEFAULT - SINCE THE RESIDUAL SPEED IS LESS THAN 10 CM/SEC
      VR=0.0
      DELTAV=0.0
  300 CONTINUE
C        COMPUTE AND PRINT FINAL VALUES
      FV1=PCA*B*(VR+DELTAV/2.0)
      FV2=PCA*C*(VR+DELTAV/2.0)**2
      SUMFT=SUMFT+FORCE*DELT *1.E-6
      PRESUR=FORCE/PCA*1.E-7
      VRP=VR/100.0
      WRITE(6,251)X,VRP,AA,FV1,FV2,FORCE,TIME,PRESUR,SUMFT
  305 CONTINUE
C        COMPUTE AND PRINT THE DIFFERENCE BETWEEN THE PREDICTED VALUE
C        AND THE EXPERIMENTAL VALUE ( DEVIANT ERROR) AND THE RELATIVE
C        ERROR
```

```
      DEVANT=VRP-VRE
      RATIO=1000.0
      IF(VRE .LE. 1.0) GOTO 302
      RATIO=DEVANT/VRE
  302 CONTINUE
      WRITE(6,310)THICK,VRE,DEVANT,RATIO
  310 FORMAT(1H0,F10.3,F10.1,3X,22H= EXPERIMENTAL VALUES   , 8X,
     1    17HSPEED DEVIANT IS ,F10.1,2X,23HRELATIVE SPEED ERROR IS,F10.3)
C         PRINT THE INPUT VALUES
      WRITE(6,315)
  315 FORMAT(1H0,16X,4HTBHN,5X,5HTHICK,5X,5HPMASS,7X,3HANG,7X,3HVSP,
     1    7X,3HVRE,5X,5HRMASS,6X,4HPDIA,6X,4HHDIA,6X,4HTRHO     )
      WRITE(6,320)TBHN,THICK,PMASS,ANG,VSP,VRE,RMASS,PDIA,HDIA,TRHO
  320 FORMAT(1H ,10HINPUT IS    ,F10.1,2F10.3,F10.1,2F10.1,3F10.3,F10.2)
C         CONTINUE WITH NEXT CASE
      IF(MOD(ICNT,2).NE.0)GOTO 100
      WRITE(6,60)
      WRITE(6,95)TGT1,TGT2,TGT3
      GOTO 100
  900 IF(NR .NE. 6HEND     )GOTO 90
      WRITE(6,901)
  901 FORMAT(1H0,20X,10HEND OF RUN   )
      STOP
      END
*     DATA
TITANIUM ALLOY
   1.0   4.48 190.0       .127    .0   1.95   .759  567.84   521.21    1.88
   2.0   4.48 190.0       .127    .0   1.95   .759 1461.82  1294.18     .91
   3.0   4.48 190.0       .318    .0   1.95   .759  880.26   590.40  -10.00
   4.0   4.48 190.0       .318    .0   1.95   .759 1355.45  1083.56    1.63
   5.0   4.48 190.0       .635    .0   1.95   .759 1491.08   683.36    1.73
   6.0   4.48 190.0       .635    .0   1.95   .759 1986.38  1127.15     .56
   7.0   4.48 190.0      1.270    .0   1.95   .759 2371.65   881.61  -10.00
   8.0   4.48 190.0       .127    .0   3.89  1.013  798.88   672.69    3.83
   9.0   4.48 190 0       .127    .0   3.89  1.013 1032.66   957.68    1.72
  10.0   4.48 190.0       .318    .0   3.89  1.013  620.27   500.79    3.83
  11.0   4.48 190.0       .318    .0   3.81  1.013  773.28   582.78    3.81
  12.0   4.48 190.0       .318    .0   3.89  1.013 1499.01  1251.81    2.43
  13.0   4.48 190.0       .635    .0   3.89  1.013 1505.71   774.50    3.24
  14.0   4.48 190.0       .635    .0   3.89  1.013 1526.13   979.32  -10.00
  15.0   4.48 190.0       .635    .0   3.89  1.013 2455.16  1367.33     .12
  16.0   4.48 190.0      1.270    .0   3.89  1.013 2551.79  1165.86     .57
  17.0   4.48 190.0       .127    .0   7.78  1.267  640.99   561.44    7.72
  18.0   4.48 190.0       .127    .0   7.78  1.267  959.21   874.78    7.72
  19.0   4.48 190.0       .318    .0   7.78  1.267  975.97   785.47    7.72
  20.0   4.48 190.0       .635    .0   7.78  1.267 1484.38   994.87  -10.00
```

RHA

1.0	7.78	135.0	.046	.0	1.95	.759	888.49	848.87	-10.00
2.0	7.78	135.0	.152	.0	1.95	.759	1211.58	1014.98	-10.00
3.0	7.78	300.0	.318	.0	1.95	.759	1521.26	1196.34	-10.00
4.0	7.78	305.0	.635	.0	1.95	.759	1394.46	460.25	-10.00
5.0	7.78	393.0	.152	.0	1.95	.759	609.90	367.89	-10.00
6.0	7.78	135.0	.046	.0	3.89	1.013	302.06	277.37	-10.00
7.0	7.78	135.0	.152	.0	3.89	1.013	393.50	256.03	-10.00
8.0	7.78	185.0	.318	.0	3.89	1.013	883.62	542.54	-10.00
9.0	7.78	300.0	.318	.0	3.89	1.013	879.65	583.69	-10.00
10.0	7.78	300.0	.318	.0	3.89	1.013	1466.09	1164.34	-10.00
11.0	7.78	300.0	.635	.0	3.89	1.013	1466.09	687.32	-10.00
12.0	7.78	300.0	.318	.0	7.78	1.267	909.52	690.37	-10.00
13.0	7.78	300.0	.318	.0	15.56	1.491	916.53	754.38	-10.00
14.0	7.78	300.0	.318	.0	15.56	1.491	1425.55	1179.58	-10.00
15.0	7.78	300.0	.635	.0	15.56	1.491	1432.56	1037.84	-10.00
16.0	7.78	305.0	.635	.0	15.56	1.491	1556.00	1109.47	-10.00
17.0	7.78	332.0	1.270	.0	15.56	1.491	1660.55	759.58	-10.00

END

SAMPLE OUTPUT FOR Z/F FORCE PENETRATION MODEL PREDICTING RESIDUAL VELOCITY

TITANIUM ALLOY

DATUM SET NR. 1 IDENTIFIER = 1.0

X (CM)	VR (M/S)	F(V0) (DYNES)	F(V1) (DYNES)	F(V2) (DYNES)	FORCE (DYNES)	TIME (MU-SEC)	PRESSURE (M PA)	IMPULSE (DYNE-SEC)
.000	567.8	5.89727E 09	1.70670E 09	3.26794E 09	1.08719E 10	.000	2402.9	.0
.001	566.6	5.89727E 09	1.70485E 09	3.26087E 09	1.08630E 10	.022	2400.9	239.4
.014	554.3	5.89727E 09	1.66785E 09	3.12088E 09	1.06860E 10	.245	2341.8	2640.4
.026	541.9	5.89727E 09	1.63064E 09	2.98317E 09	1.05111E 10	.473	2323.1	5055.5
.039	529.5	5.89727E 09	1.59319E 09	2.84772E 09	1.03382E 10	.706	2284.9	7486.0
.051	516.9	5.89727E 09	1.55548E 09	2.71450E 09	1.01673E 10	.945	2247.1	9933.6
.064	504.3	5.89727E 09	1.51748E 09	2.58349E 09	9.99825E 09	1.190	2209.8	12399.9
.076	491.5	5.89727E 09	1.47916E 09	2.45467E 09	9.83111E 09	1.441	2172.8	14887.1
.089	478.0	5.89727E 09	1.43758E 09	2.31859E 09	9.65344E 09	1.712	2133.6	17523.2
.102	465.0	5.89727E 09	1.39849E 09	2.19422E 09	9.48999E 09	1.977	2097.5	20059.8
.114	451.5	5.89727E 09	1.35897E 09	2.07197E 09	9.32821E 09	2.250	2061.7	22624.4
.127	438.4	5.89727E 09	1.31777E 09	1.94823E 09	9.16327E 09	2.534	2025.2	25272.4

.127 521.2 = EXPERIMENTAL VALUES SPEED DEVIANT IS -82.8 RELATIVE SPEED ERROR IS -.159

	TBHN	THICK	PMASS	ANG	VSP	VRE	RMASS	PDIA	HDIA	TRHO
INPUT IS	190.0	.127	1.950	.0	567.8	521.2	1.880	.759	.000	4.48

DATUM SET NR. 2 IDENTIFIER = 2.0

X (CM)	VR (M/S)	F(V0) (DYNES)	F(V1) (DYNES)	F(V2) (DYNES)	FORCE (DYNES)	TIME (MU-SEC)	PRESSURE (M PA)	IMPULSE (DYNE-SEC)
.000	1461.8	5.89727E 09	4.39364E 09	2.16575E 10	3.19485E 10	.000	7061.2	.0
.003	1459.0	5.89727E 09	4.38943E 09	2.16161E 10	3.19028E 10	.017	7051.1	546.1
.015	1445.1	5.89727E 09	4.34744E 09	2.12045E 10	3.14492E 10	.103	6950.8	3269.0
.028	1431.2	5.89727E 09	4.30565E 09	2.07988E 10	3.10017E 10	.190	6851.9	5979.2
.040	1417.3	5.89727E 09	4.26405E 09	2.03988E 10	3.05601E 10	.278	6754.3	8676.8
.053	1403.6	5.89727E 09	4.22264E 09	2.00046E 10	3.01245E 10	.367	6658.0	11362.0
.065	1389.8	5.89727E 09	4.18142E 09	1.96160E 10	2.96947E 10	.456	6563.0	14034.9
.078	1376.2	5.89727E 09	4.14039E 09	1.92329E 10	2.92705E 10	.546	6469.3	16695.7
.090	1362.6	5.89727E 09	4.09955E 09	1.88553E 10	2.88521E 10	.638	6376.8	19344.6
.103	1349.1	5.89727E 09	4.05888E 09	1.84831E 10	2.84392E 10	.730	6285.6	21981.7
.115	1335.6	5.89727E 09	4.01840E 09	1.81162E 10	2.80319E 10	.823	6195.5	24607.1
.127	1322.2	5.89727E 09	3.97839E 09	1.77618E 10	2.76379E 10	.913	6108.5	27534.3

.127 1294.2 = EXPERIMENTAL VALUES SPEED DEVIANT IS 28.6 RELATIVE SPEED ERROR IS .022

	TBHN	THICK	PMASS	ANG	VSP	VRE	RMASS	PDIA	HDIA	TRHO
INPUT IS	190.0	.127	1.950	.0	1461.8	1294.2	.910	.759	.000	4.48

SAMPLE OUTPUT FOR Z/F FORCE PENETRATION MODEL PREDICTING RESIDUAL VELOCITY

TITANIUM ALLOY

DATUM SET NR. 3 IDENTIFIER = 3.0

X (CM)	VR (M/S)	F(V0) (DYNES)	F(V1) (DYNES)	F(V2) (DYNES)	FORCE (DYNES)	TIME (MU-SEC)	PRESSURE (M PA)	IMPULSE (DYNE-SEC)
.000	880.3	5.89727E 09	2.64570E 09	7.55314E 09	1.63961E 10	.000	3623.8	.0
.005	875.5	5.89727E 09	2.63853E 09	7.81060E 09	1.63464E 10	.057	3612.8	931.0
.035	846.9	5.89727E 09	2.55258E 09	7.31004E 09	1.57599E 10	.405	3483.2	6505.7
.065	818.4	5.89727E 09	2.46689E 09	6.62748E 09	1.51917E 10	.766	3357.6	12064.0
.100	785.2	5.89727E 09	2.36714E 09	6.28651E 09	1.45510E 10	1.202	3216.0	18534.8
.130	756.8	5.89727E 09	2.28174E 09	5.64106E 09	1.40201E 10	1.591	3098.7	24075.6
.160	728.4	5.89727E 09	2.19632E 09	5.41191E 09	1.35056E 10	1.995	2985.0	29617.9
.195	695.2	5.89727E 09	2.09650E 09	4.93118E 09	1.29250E 10	2.487	2856.7	36095.0
.225	666.6	5.89727E 09	2.01066E 09	4.53566E 09	1.24437E 10	2.928	2750.3	41665.7
.255	637.9	5.89727E 09	1.92082E 09	4.13939E 09	1.19575E 10	3.383	2642.8	47263.4
.288	606.6	5.89727E 09	1.82672E 09	3.74374E 09	1.14678E 10	3.910	2534.6	53370.6
.318	576.9	5.89727E 09	1.73454E 09	3.37582E 09	1.10077E 10	4.426	2432.9	59252.1

.318 590.4 = EXPERIMENTAL VALUES SPEED DEVIANT IS -13.5 RELATIVE SPEED ERROR IS -.023

	TBHN	THICK	PMASS	ANG	VSP	VRE	RMASS	PDIA	HDIA	TRHO
INPUT IS	190.0	.318	1.950	.0	880.3	590.4	-10.000	.759	.000	4.48

DATUM SET NR. 4 IDENTIFIER = 4.0

X (CM)	VR (M/S)	F(V0) (DYNES)	F(V1) (DYNES)	F(V2) (DYNES)	FORCE (DYNES)	TIME (MU-SEC)	PRESSURE (M PA)	IMPULSE (DYNE-SEC)
.000	1355.5	5.89727E 09	4.07393E 09	1.86204E 10	2.85916E 10	.000	6319.2	.0
.003	1352.7	5.89727E 09	4.06987E 09	1.85833E 10	2.85504E 10	.018	6310.1	527.1
.033	1320.5	5.89727E 09	3.97289E 09	1.77082E 10	2.75783E 10	.243	6095.3	6816.4
.065	1285.9	5.89727E 09	3.86896E 09	1.67938E 10	2.65600E 10	.492	5870.2	13556.5
.098	1251.7	5.89727E 09	3.76616E 09	1.59132E 10	2.55766E 10	.748	5652.9	20223.2
.128	1220.5	5.89727E 09	3.67223E 09	1.51294E 10	2.46989E 10	.991	5458.9	26314.6
.160	1187.0	5.89727E 09	3.57148E 09	1.43106E 10	2.37794E 10	1.261	5255.7	32848.6
.193	1153.8	5.89727E 09	3.47173E 09	1.35223E 10	2.28913E 10	1.539	5059.4	39318.2
.225	1121.0	5.89727E 09	3.37292E 09	1.27636E 10	2.20338E 10	1.825	4869.8	45726.6
.255	1090.9	5.89727E 09	3.28250E 09	1.20885E 10	2.12682E 10	2.096	4700.7	51590.6
.288	1058.6	5.89727E 09	3.18536E 09	1.13836E 10	2.04662E 10	2.398	4523.4	57890.9
.318	1026.5	5.89727E 09	3.09196E 09	1.07258E 10	1.97150E 10	2.691	4357.4	63852.9

.318 1083.6 = EXPERIMENTAL VALUES SPEED DEVIANT IS -55.1 RELATIVE SPEED ERROR IS -.051

	TBHN	THICK	PMASS	ANG	VSP	VRE	RMASS	PDIA	HDIA	TRHO
INPUT IS	190.0	.318	1.950	.0	1355.5	1083.6	1.630	.759	.000	4.48

SAMPLE OUTPUT FOR Z/F FORCE PENETRATION MODEL PREDICTING RESIDUAL VELOCITY

TITANIUM ALLOY

DATUM SET NR. 5 IDENTIFIER = 5.0

X (CM)	VR (M/S)	F(V0) (DYNES)	F(V1) (DYNES)	F(V2) (DYNES)	FORCE (DYNES)	TIME (MU-SEC)	PRESSURE (M PA)	IMPULSE (DYNE-SEC)
.000	1491.1	5.89727E 09	4.48158E 09	2.25332E 10	3.29121E 10	.000	7274.1	.0
.003	1486.3	5.89727E 09	4.47733E 09	2.24905E 10	3.28651E 10	.017	7263.8	551.6
.065	1418.4	5.89727E 09	4.26730E 09	2.04299E 10	3.05945E 10	.447	6761.9	14171.9
.128	1350.1	5.89727E 09	4.06206E 09	1.85120E 10	2.84713E 10	.899	6292.7	27481.4
.193	1280.7	5.89727E 09	3.85337E 09	1.66588E 10	2.64094E 10	1.393	5836.9	41015.0
.255	1215.4	5.89727E 09	3.65696E 09	1.50038E 10	2.45581E 10	1.894	5427.8	53752.7
.318	1151.4	5.89727E 09	3.46438E 09	1.34652E 10	2.28269E 10	2.422	5045.1	66242.2
.383	1086.0	5.89727E 09	3.26779E 09	1.19803E 10	2.11454E 10	3.003	4673.5	78992.6
.445	1024.2	5.89727E 09	3.08191E 09	1.06562E 10	1.96354E 10	3.596	4339.8	91048.5
.510	960.8	5.89727E 09	2.89143E 09	9.37962E 09	1.81683E 10	4.251	4015.5	103403.7
.573	900.6	5.89727E 09	2.71051E 09	8.24256E 09	1.68503E 10	4.923	3724.2	115139.1
.635	841.0	5.89727E 09	2.53124E 09	7.18834E 09	1.56169E 10	5.641	3451.6	127231.4

.635 683.4 = EXPERIMENTAL VALUES SPEED DEVIANT IS 157.6 RELATIVE SPEED ERROR IS .231

	TBHN	THICK	PMASS	ANG	VSP	VRE	RMASS	PDIA	HDIA	TRHO
INPUT IS	190.0	.635	1.950	.0	1491.1	683.4	1.730	.759	.000	4.48

DATUM SET NR. 6 IDENTIFIER = 6.0

X (CM)	VR (M/S)	F(V0) (DYNES)	F(V1) (DYNES)	F(V2) (DYNES)	FORCE (DYNES)	TIME (MU-SEC)	PRESSURE (M PA)	IMPULSE (DYNE-SEC)
.000	1986.4	5.89727E 09	5.97025E 09	3.99895E 10	5.18570E 10	.000	11461.3	.0
.001	1984.7	5.89727E 09	5.96773E 09	3.99558E 10	5.18208E 10	.006	11453.3	326.2
.064	1902.2	5.89727E 09	5.71975E 09	3.67041E 10	4.83211E 10	.328	10679.8	16411.1
.128	1820.4	5.89727E 09	5.47367E 09	3.36138E 10	4.49848E 10	.671	9942.4	32372.2
.191	1740.7	5.89727E 09	5.23422E 09	3.07372E 10	4.18687E 10	1.029	9253.7	47908.2
.255	1663.2	5.89727E 09	5.00110E 09	2.80602E 10	3.89586E 10	1.403	8610.5	63024.1
.318	1589.1	5.89727E 09	4.77839E 09	2.56168E 10	3.62924E 10	1.788	8021.3	77469.3
.381	1515.4	5.89727E 09	4.55639E 09	2.32970E 10	3.37511E 10	2.199	7459.6	91836.3
.445	1443.5	5.89727E 09	4.34091E 09	2.11399E 10	3.13780E 10	2.630	6935.1	105852.2
.509	1373.4	5.89727E 09	4.12983E 09	1.91348E 10	2.91619E 10	3.082	6445.3	119537.5
.573	1304.8	5.89727E 09	3.92362E 09	1.72717E 10	2.70926E 10	3.559	5987.9	132913.0
.635	1239.0	5.89727E 09	3.72578E 09	1.55738E 10	2.51969E 10	4.050	5569.0	146000.1

.635 1127.1 = EXPERIMENTAL VALUES SPEED DEVIANT IS 111.8 RELATIVE SPEED ERROR IS .099

	TBHN	THICK	PMASS	ANG	VSP	VRE	RMASS	PDIA	HDIA	TRHO
INPUT IS	190.0	.635	1.950	.0	1986.4	1127.1	.560	.759	.000	4.48

SAMPLE OUTPUT FOR Z/F FORCE PENETRATION MODEL PREDICTING RESIDUAL VELOCITY

TITANIUM ALLOY

DATUM SET NR. 7 IDENTIFIER = 7.0

X (CM)	VR (M/S)	F(V0) (DYNES)	F(V1) (DYNES)	F(V2) (DYNES)	FORCE (DYNES)	TIME (MU-SEC)	PRESSURE (M PA)	IMPULSE (DYNE-SEC)
.000	2371.7	5.89727E 09	7.12821E 09	5.70063E 10	7.00318E 10	.000	15478.2	.0
.001	2359.8	5.89727E 09	7.12537E 09	5.69608E 10	6.99834E 10	.005	15467.6	369.0
.128	2184.2	5.89727E 09	6.56739E 09	4.83891E 10	6.08537E 10	.560	13449.7	36559.5
.255	2007.3	5.89727E 09	6.03558E 09	4.08695E 10	5.28024E 10	1.169	11670.3	71053.1
.381	1841.7	5.89727E 09	5.53787E 09	3.44070E 10	4.58422E 10	1.826	10131.9	103335.2
.509	1683.4	5.89727E 09	5.06195E 09	2.87473E 10	3.97065E 10	2.550	8775.8	134204.8
.635	1534.7	5.89727E 09	4.61474E 09	2.38922E 10	3.44042E 10	3.336	7603.9	163211.9
.763	1391.7	5.89727E 09	4.18496E 09	1.96492E 10	2.97314E 10	4.208	6571.2	191088.9
.890	1255.2	5.89727E 09	3.77463E 09	1.59849E 10	2.56568E 10	5.173	5670.6	217704.9
1.016	1125.5	5.89727E 09	3.38435E 09	1.28541E 10	2.21352E 10	6.235	4892.5	242988.4
1.144	999.2	5.89727E 09	3.00495E 09	1.01306E 10	1.90328E 10	7.437	4206.6	267632.4
1.270	877.4	5.89727E 09	2.63712E 09	7.80227E 09	1.63367E 10	8.784	3610.7	291377.9

1.270 381.6 = EXPERIMENTAL VALUES SPEED DEVIANT IS 495.8 RELATIVE SPEED ERROR IS 1.299

	TBHN	THICK	PMASS	ANG	VSP	VRE	RMASS	PDIA	HDIA	TRHO
INPUT IS	190.0	1.270	1.550	.0	2371.7	381.6	-10.000	.759	.000	4.48

DATUM SET NR. 8 IDENTIFIER = 8.0

X (CM)	VR (M/S)	F(V0) (DYNES)	F(V1) (DYNES)	F(V2) (DYNES)	FORCE (DYNES)	TIME (MU-SEC)	PRESSURE (M PA)	IMPULSE (DYNE-SEC)
.000	798.9	1.05045E 10	4.27708E 09	1.15218E 10	2.63036E 10	.000	3263.7	.0
.010	790.4	1.05045E 10	4.25442E 09	1.14001E 10	2.61595E 10	.126	3245.8	3292.0
.020	782.0	1.05045E 10	4.20912E 09	1.11586E 10	2.58728E 10	.253	3210.2	6582.9
.030	773.5	1.05045E 10	4.16383E 09	1.09198E 10	2.55887E 10	.382	3175.0	9873.1
.040	765.0	1.05045E 10	4.11855E 09	1.06835E 10	2.53072E 10	.512	3140.0	13162.8
.060	748.1	1.05045E 10	4.02800E 09	1.02159E 10	2.47520E 10	.776	3071.2	19742.4
.070	739.7	1.05045E 10	3.98272E 09	9.99044E 09	2.44783E 10	.910	3037.2	23033.0
.080	731.2	1.05045E 10	3.93742E 09	9.76449E 09	2.42070E 10	1.046	3003.5	26324.5
.090	722.7	1.05045E 10	3.89211E 09	9.54105E 09	2.39383E 10	1.184	2970.2	29617.3
.110	705.8	1.05045E 10	3.80142E 09	9.10160E 09	2.34082E 10	1.464	2904.4	36208.7
.120	697.3	1.05045E 10	3.75603E 09	8.88554E 09	2.31467E 10	1.606	2872.0	39508.0
.127	691.4	1.05045E 10	3.71742E 09	8.70380E 09	2.29262E 10	1.707	2844.6	44130.6

.127 672.7 = EXPERIMENTAL VALUES SPEED DEVIANT IS 18.7 RELATIVE SPEED ERROR IS .028

	TBHN	THICK	PMASS	ANG	VSP	VRE	RMASS	PDIA	HDIA	TRHO
INPUT IS	190.0	.127	3.390	.0	798.9	672.7	3.830	1.013	.000	4.48

SAMPLE OUTPUT FOR 2/F FORCE PENETRATION MODEL PREDICTING RESIDUAL VELOCITY

TITANIUM ALLOY

DATUM SET NR. 9 IDENTIFIER = 9.0

X (CM)	VR (M/S)	F(V3) (DYNES)	F(V1) (DYNES)	F(V2) (DYNES)	FORCE (DYNES)	TIME (MU-SEC)	PRESSURE (M PA)	IMPULSE (DYNE-SEC)
.000	1032.7	1.05043E 10	5.52870E 09	1.92518E 10	3.52853E 10	.000	4378.1	.0
.003	1030.5	1.05043E 10	5.52282E 09	1.92109E 10	3.52385E 10	.024	4372.3	854.0
.015	1019.5	1.05043E 10	5.46413E 09	1.88048E 10	3.47737E 10	.146	4314.6	5117.4
.028	1008.6	1.05043E 10	5.40559E 09	1.84040E 10	3.43143E 10	.269	4257.6	9369.9
.040	997.7	1.05043E 10	5.34719E 09	1.80085E 10	3.38604E 10	.394	4201.3	13611.8
.053	986.8	1.05043E 10	5.28893E 09	1.76182E 10	3.34119E 10	.520	4145.7	17843.6
.065	975.9	1.05043E 10	5.23081E 09	1.72331E 10	3.29687E 10	.647	4090.7	22065.5
.078	965.1	1.05043E 10	5.17283E 09	1.68532E 10	3.25308E 10	.776	4036.3	26277.8
.090	954.3	1.05043E 10	5.11498E 09	1.64782E 10	3.20980E 10	.906	3982.6	30481.0
.103	943.5	1.05043E 10	5.05722E 09	1.61083E 10	3.16703E 10	1.038	3929.6	34675.5
.115	932.8	1.05043E 10	4.99960E 09	1.57433E 10	3.12477E 10	1.171	3877.1	38861.4
.127	922.4	1.05043E 10	4.94324E 09	1.53904E 10	3.08384E 10	1.301	3826.3	43540.4

.127 957.7 = EXPERIMENTAL VALUES SPEED DEVIANT IS -35.2 RELATIVE SPEED ERROR IS -.037

	TBHR	THICK	PMASS	ANG	VSP	VRE	RMASS	PDIA	HDIA	TRHO
INPUT IS	190.0	.127	3.890	.0	1032.7	957.7	1.720	1.013	.000	4.48

DATUM SET NR. 10 IDENTIFIER = 10.0

X (CM)	VR (M/S)	F(V3) (DYNES)	F(V1) (DYNES)	F(V2) (DYNES)	FORCE (DYNES)	TIME (MU-SEC)	PRESSURE (M PA)	IMPULSE (DYNE-SEC)
.000	620.3	1.05043E 10	3.32083E 09	6.94574E 09	2.07713E 10	.000	2577.2	.0
.003	618.1	1.05043E 10	3.31506E 09	6.92165E 09	2.07415E 10	.040	2573.5	837.4
.033	592.2	1.05043E 10	3.17621E 09	6.35397E 09	2.00350E 10	.536	2485.9	10929.5
.065	563.8	1.05043E 10	3.02435E 09	5.76088E 09	1.92900E 10	1.099	2393.4	21968.7
.096	536.2	1.05043E 10	2.87355E 09	5.20073E 09	1.85791E 10	1.667	2305.2	32714.4
.128	508.1	1.05043E 10	2.72349E 09	4.67172E 09	1.79000E 10	2.265	2221.0	43621.5
.160	478.4	1.05043E 10	2.56449E 09	4.14217E 09	1.72114E 10	2.924	2135.5	55178.6
.191	449.2	1.05043E 10	2.40651E 09	3.64754E 09	1.65588E 10	3.598	2054.6	66947.9
.223	418.5	1.05043E 10	2.24246E 09	3.16720E 09	1.59144E 10	4.333	1974.6	78470.9
.255	386.8	1.05043E 10	2.07266E 09	2.70572E 09	1.52832E 10	5.125	1896.3	90812.7
.286	354.4	1.05043E 10	1.89809E 09	2.26913E 09	1.46720E 10	5.968	1820.5	103438.0
.318	319.6	1.05043E 10	1.71150E 09	1.64493E 09	1.40612E 10	6.911	1744.7	117054.3

.318 500.6 = EXPERIMENTAL VALUES SPEED DEVIANT IS -191.2 RELATIVE SPEED ERROR IS -.362

	TBHR	THICK	PMASS	ANG	VSP	VRE	RMASS	PDIA	HDIA	TRHO
INPUT IS	190.0	.318	3.390	.0	620.3	500.8	3.830	1.013	.000	4.48

SAMPLE OUTPUT FOR 3/E FORCE PENETRATION MODEL PREDICTING RESIDUAL VELOCITY

TITANIUM ALLOY

DATUM SET NR. 11 IDENTIFIER = 11.0

X (CM)	VR (M/S)	F(V0) (DYNES)	F(V1) (DYNES)	F(V2) (DYNES)	FORCE (DYNES)	TIME (MU-SEC)	PRESSURE (M PA)	IMPULSE (DYNE-SEC)
.000	773.3	1.05048E 10	4.14002E 09	1.07952E 10	2.54430E 10	.000	3156.5	.0
.010	764.6	1.05048E 10	4.11738E 09	1.06775E 10	2.52999E 10	.130	3139.1	3289.8
.040	739.4	1.05048E 10	3.98154E 09	9.98454E 09	2.44712E 10	.529	3036.3	13159.9
.070	714.1	1.05048E 10	3.84560E 09	9.31439E 09	2.36651E 10	.942	2936.3	23039.0
.100	688.6	1.05048E 10	3.70942E 09	8.66636E 09	2.28810E 10	1.370	2839.0	32937.7
.130	663.1	1.05048E 10	3.56143E 09	7.98869E 09	2.20550E 10	1.813	2736.5	42867.7
.160	637.4	1.05048E 10	3.42421E 09	7.38491E 09	2.13140E 10	2.275	2644.6	52842.7
.193	609.5	1.05048E 10	3.26856E 09	6.72999E 09	2.05036E 10	2.796	2544.0	63717.6
.225	581.3	1.05048E 10	3.11794E 09	6.12296E 09	1.97457E 10	3.342	2450.0	74686.1
.255	555.0	1.05048E 10	2.97425E 09	5.57159E 09	1.90506E 10	3.870	2363.7	84917.2
.286	527.2	1.05048E 10	2.82573E 09	5.02908E 09	1.83596E 10	4.443	2278.0	95710.8
.316	498.6	1.05048E 10	2.67059E 09	4.49200E 09	1.76674E 10	5.067	2192.1	107031.7

.318 582.8 = EXPERIMENTAL VALUES SPEED DEVIANT IS -84.2 RELATIVE SPEED ERROR IS -.144

	TBHN	THICK	PMASS	ANG	VSP	VRE	RMASS	PDIA	HDIA	TRHO
INPUT IS	190.0	.318	3.890	.0	773.3	582.8	3.810	1.013	.000	4.48

DATUM SET NR. 12 IDENTIFIER = 12.0

X (CM)	VR (M/S)	F(V0) (DYNES)	F(V1) (DYNES)	F(V2) (DYNES)	FORCE (DYNES)	TIME (MU-SEC)	PRESSURE (M PA)	IMPULSE (DYNE-SEC)
.000	1499.0	1.05048E 10	8.02546E 09	4.05663E 10	5.90966E 10	.000	7332.5	.0
.003	1496.5	1.05048E 10	8.01868E 09	4.04978E 10	5.90213E 10	.017	7323.2	985.2
.033	1466.3	1.05048E 10	7.85631E 09	3.88793E 10	5.72408E 10	.219	7102.3	12741.7
.065	1433.9	1.05048E 10	7.68329E 09	3.71809E 10	5.53689E 10	.443	6870.0	25344.1
.098	1401.8	1.05048E 10	7.51163E 09	3.55381E 10	5.35545E 10	.673	6644.9	37810.9
.128	1372.5	1.05048E 10	7.35430E 09	3.40696E 10	5.19292E 10	.889	6443.2	49201.8
.160	1341.1	1.05048E 10	7.18658E 09	3.25290E 10	5.02234E 10	1.126	6231.2	61418.9
.193	1310.0	1.05048E 10	7.02008E 09	3.10392E 10	4.85640E 10	1.374	6025.7	73512.0
.225	1279.3	1.05048E 10	6.85523E 09	2.95965E 10	4.69555E 10	1.625	5826.5	85465.2
.255	1251.1	1.05048E 10	6.70448E 09	2.83110E 10	4.55203E 10	1.862	5648.0	96434.5
.288	1220.9	1.05048E 10	6.54265E 09	2.69608E 10	4.40082E 10	2.125	5460.4	108188.7
.318	1192.8	1.05048E 10	6.38721E 09	2.56950E 10	4.25869E 10	2.378	5284.1	119300.2

.318 1251.0 = EXPERIMENTAL VALUES SPEED DEVIANT IS -59.0 RELATIVE SPEED ERROR IS -.047

	TBHN	THICK	PMASS	ANG	VSP	VRE	RMASS	PDIA	HDIA	TRHO
INPUT IS	190.0	.318	3.390	.0	1499.0	1251.8	2.430	1.013	.000	4.48

SAMPLE OUTPUT FOR Z/F FORCE PENETRATION MODEL PREDICTING RESIDUAL VELOCITY

TITANIUM ALLOY

DATUM SET NR. 13 IDENTIFIER = 13.0

X (CM)	VR (M/S)	F(V0) (DYNES)	F(V1) (DYNES)	F(V2) (DYNES)	FORCE (DYNES)	TIME (MU-SEC)	PRESSURE (M PA)	IMPULSE (DYNE-SEC)
.000	1505.7	1.05045E 10	8.06133E 09	4.09298E 10	5.94959E 10	.000	7382.1	.0
.003	1503.2	1.05045E 10	8.05454E 09	4.08608E 10	5.94201E 10	.017	7372.7	987.4
.065	1440.4	1.05045E 10	7.71839E 09	3.75214E 10	5.57446E 10	.441	6916.6	25400.9
.128	1378.9	1.05045E 10	7.38919E 09	3.43890E 10	5.22829E 10	.885	6487.1	49310.2
.193	1316.3	1.05045E 10	7.05378E 09	3.13378E 10	4.88964E 10	1.367	6066.9	73671.1
.255	1257.3	1.05045E 10	6.73755E 09	2.85910E 10	4.58333E 10	1.853	5686.9	96639.0
.318	1199.3	1.05045E 10	6.42736E 09	2.60166E 10	4.29485E 10	2.362	5328.9	119190.0
.383	1140.1	1.05045E 10	6.10930E 09	2.35115E 10	4.01261E 10	2.918	4978.7	142234.1
.445	1084.0	1.05045E 10	5.80969E 09	2.12585E 10	3.75730E 10	3.480	4661.9	164032.6
.510	1026.5	1.05045E 10	5.50221E 09	1.90678E 10	3.50747E 10	4.096	4352.0	186367.8
.573	972.1	1.05045E 10	5.21045E 09	1.70992E 10	3.28144E 10	4.722	4071.5	207561.2
.635	918.3	1.05045E 10	4.92193E 09	1.52580E 10	3.06847E 10	5.383	3807.3	229354.6

.635 774.5 = EXPERIMENTAL VALUES SPEED DEVIANT IS 143.8 RELATIVE SPEED ERROR IS .186

	TBHN	THICK	PMASS	ANG	VSP	VRE	RMASS	PDIA	HDIA	TRHO
INPUT IS	190.0	.635	3.890	.0	1505.7	774.5	3.240	1.013	.000	4.48

DATUM SET NR. 14 IDENTIFIER = 14.0

X (CM)	VR (M/S)	F(V0) (DYNES)	F(V1) (DYNES)	F(V2) (DYNES)	FORCE (DYNES)	TIME (MU-SEC)	PRESSURE (M PA)	IMPULSE (DYNE-SEC)
.000	1526.1	1.05045E 10	8.17056E 09	4.20475E 10	6.07229E 10	.000	7534.3	.0
.003	1523.6	1.05045E 10	8.16381E 09	4.19771E 10	6.06457E 10	.016	7524.7	994.3
.065	1460.4	1.05045E 10	7.82536E 09	3.85687E 10	5.68938E 10	.435	7059.8	25575.1
.128	1398.5	1.05045E 10	7.49397E 09	3.53712E 10	5.33700E 10	.873	6622.0	49643.1
.193	1335.5	1.05045E 10	7.15642E 09	3.22565E 10	4.99177E 10	1.348	6193.6	74159.3
.255	1276.1	1.05045E 10	6.83826E 09	2.94522E 10	4.67952E 10	1.827	5806.2	97267.2
.318	1217.6	1.05045E 10	6.52598E 09	2.68237E 10	4.38544E 10	2.328	5441.3	119948.6
.383	1158.2	1.05045E 10	6.20700E 09	2.42655E 10	4.09773E 10	2.876	5084.3	143117.5
.445	1101.9	1.05045E 10	5.90539E 09	2.19646E 10	3.83747E 10	3.429	4761.4	165025.0
.510	1044.2	1.05045E 10	5.59651E 09	1.97269E 10	3.58282E 10	4.035	4445.5	187461.4
.573	989.5	1.05045E 10	5.30359E 09	1.77160E 10	3.35243E 10	4.650	4159.6	208739.0
.635	935.5	1.05045E 10	5.01410E 09	1.58348E 10	3.13536E 10	5.299	3890.3	230605.2

.635 979.3 = EXPERIMENTAL VALUES SPEED DEVIANT IS -43.9 RELATIVE SPEED ERROR IS -.045

	TBHN	THICK	PMASS	ANG	VSP	VRE	RMASS	PDIA	HDIA	TRHO
INPUT IS	190.0	.635	3.890	.0	1526.1	979.3	-10.000	1.013	.000	4.48

SAMPLE OUTPUT FOR Z/F FORCE PENETRATION MODEL PREDICTING RESIDUAL VELOCITY

TITANIUM ALLOY

DATUM SET NR. 15 IDENTIFIER = 15.0

X (CM)	VR (M/S)	F(V0) (DYNES)	F(V1) (DYNES)	F(V2) (DYNES)	FORCE (DYNES)	TIME (MU-SEC)	PRESSURE (M PA)	IMPULSE (DYNE-SEC)
.000	2455.2	1.05048E 10	1.31445E 10	1.08822E 11	1.32471E 11	.000	16436.6	.0
.001	2453.4	1.05048E 10	1.31399E 10	1.08745E 11	1.32390E 11	.005	16426.5	674.3
.064	2367.9	1.05048E 10	1.26819E 10	1.01297E 11	1.24483E 11	.264	15445.3	33942.6
.128	2282.9	1.05048E 10	1.22269E 10	9.41575E 10	1.16889E 11	.539	14503.3	66997.1
.191	2200.2	1.05048E 10	1.17836E 10	8.74545E 10	1.09743E 11	.823	13616.6	99194.2
.255	2119.5	1.05048E 10	1.13518E 10	8.11618E 10	1.03018E 11	1.118	12782.2	130564.0
.318	2042.4	1.05048E 10	1.09390E 10	7.53673E 10	9.68111E 10	1.419	12012.0	160544.4
.381	1965.8	1.05048E 10	1.05235E 10	6.93170E 10	9.08502E 10	1.737	11272.4	190363.2
.445	1891.0	1.05048E 10	1.01232E 10	6.46088E 10	8.52417E 10	2.067	10576.5	219442.0
.509	1818.1	1.05048E 10	9.73770E 09	5.97225E 10	7.99650E 10	2.411	9921.8	247809.4
.573	1747.0	1.05048E 10	9.35658E 09	5.51392E 10	7.50006E 10	2.762	9305.8	275493.7
.635	1678.8	1.05048E 10	8.99170E 09	5.09225E 10	7.04190E 10	3.134	8737.4	302523.2

.635 1367.3 = EXPERIMENTAL VALUES SPEED DEVIANT IS 311. RELATIVE SPEED ERROR IS .228

	TBHN	THICK	PMASS	ANG	VSP	VRE	RMASS	PDIA	HDIA	TRHO
INPUT IS	190.0	.635	3.890	.0	2455.2	1367.3	.120	1.013	.000	4.48

DATUM SET NR. 16 IDENTIFIER = 16.0

X (CM)	VR (M/S)	F(V0) (DYNES)	F(V1) (DYNES)	F(V2) (DYNES)	FORCE (DYNES)	TIME (MU-SEC)	PRESSURE (M PA)	IMPULSE (DYNE-SEC)
.000	2551.8	1.05048E 10	1.36619E 10	1.17557E 11	1.41723E 11	.000	17584.6	.0
.001	2550.0	1.05048E 10	1.36571E 10	1.17474E 11	1.41636E 11	.005	17573.8	694.1
.128	2374.5	1.05048E 10	1.27175E 10	1.01866E 11	1.25088E 11	.518	15520.6	68946.7
.255	2206.5	1.05048E 10	1.18174E 10	8.79564E 10	1.10279E 11	1.075	13683.0	134330.7
.381	2048.4	1.05048E 10	1.09711E 10	7.58101E 10	9.72860E 10	1.669	12070.9	195802.9
.509	1896.7	1.05048E 10	1.01537E 10	6.49986E 10	8.56621E 10	2.316	10628.7	254814.8
.635	1753.8	1.05048E 10	9.39304E 09	5.55697E 10	7.54675E 10	3.008	9363.8	310434.5
.763	1616.1	1.05048E 10	8.65591E 09	4.71891E 10	6.63497E 10	3.766	8232.5	363987.8
.890	1484.6	1.05048E 10	7.95171E 09	3.98242E 10	5.92806E 10	4.589	7231.3	415135.5
1.016	1359.9	1.05048E 10	7.28406E 09	3.34175E 10	5.12063E 10	5.477	6353.5	463635.1
1.144	1239.0	1.05048E 10	6.63645E 09	2.77294E 10	4.45806E 10	6.459	5568.7	510680.7
1.270	1123.5	1.05048E 10	6.01517E 09	2.27888E 10	3.93088E 10	7.529	4877.3	555595.3

1.270 1165.9 = EXPERIMENTAL VALUES SPEED DEVIANT IS -42.3 RELATIVE SPEED ERROR IS -.036

	TBHN	THICK	PMASS	ANG	VSP	VRE	RMASS	PDIA	HDIA	TRHO
INPUT IS	190.0	1.270	3.890	.0	2551.8	1165.9	.570	1.013	.000	4.48

SAMPLE OUTPUT FOR Z/F FORCE PENETRATION MODEL PREDICTING RESIDUAL VELOCITY

TITANIUM ALLOY

DATUM SET NR. 17 IDENTIFIER = 17.0

X (CM)	VR (M/S)	F(V0) (DYNES)	F(V1) (DYNES)	F(V2) (DYNES)	FORCE (DYNES)	TIME (MU-SEC)	PRESSURE (M PA)	IMPULSE (DYNE-SEC)
.000	641.0	1.64332E 10	5.36848E 09	1.16036E 10	3.36053E 10	.000	2649.5	.0
.005	637.6	1.64332E 10	5.35445E 09	1.15430E 10	3.33308E 10	.078	2643.6	2606.8
.015	630.9	1.64332E 10	5.29828E 09	1.13021E 10	3.30337E 10	.236	2620.1	7826.5
.030	620.8	1.64332E 10	5.21385E 09	1.09448E 10	3.25919E 10	.476	2585.0	15672.6
.040	614.1	1.64332E 10	5.15744E 09	1.07093E 10	3.23000E 10	.637	2561.9	20915.4
.053	605.7	1.64332E 10	5.07969E 09	1.03888E 10	3.19017E 10	.842	2530.3	27483.5
.065	597.2	1.64332E 10	5.00882E 09	1.01009E 10	3.15429E 10	1.050	2501.8	34069.1
.078	588.7	1.64332E 10	4.93774E 09	9.81630E 09	3.11872E 10	1.261	2473.6	40673.5
.090	580.2	1.64332E 10	4.86644E 09	9.53487E 09	3.08345E 10	1.475	2445.6	47298.4
.103	571.7	1.64332E 10	4.79491E 09	9.25663E 09	3.04847E 10	1.692	2417.9	53945.2
.115	563.1	1.64332E 10	4.72313E 09	8.98156E 09	3.01379E 10	1.912	2390.4	60615.6
.127	554.8	1.64332E 10	4.65252E 09	8.71503E 09	2.98007E 10	2.127	2363.7	68115.9

.127 561.4 = EXPERIMENTAL VALUES SPEED DEVIANT IS -6.6 RELATIVE SPEED ERROR IS -.012

	TBHN	THICK	PMASS	ANG	VSP	VRE	RMASS	PDIA	HDIA	TRHO
INPUT IS	190.0	.127	7.780	.0	641.0	561.4	7.720	1.267	.000	4.48

DATUM SET NR. 18 IDENTIFIER = 18.0

X (CM)	VR (M/S)	F(V0) (DYNES)	F(V1) (DYNES)	F(V2) (DYNES)	FORCE (DYNES)	TIME (MU-SEC)	PRESSURE (M PA)	IMPULSE (DYNE-SEC)
.000	959.2	1.64332E 10	8.03366E 09	2.59847E 10	5.04516E 10	.000	4001.6	.0
.005	955.8	1.64332E 10	8.01951E 09	2.58933E 10	5.03460E 10	.052	3993.2	2629.0
.015	949.1	1.64332E 10	7.96294E 09	2.55293E 10	4.99254E 10	.157	3959.9	7881.8
.030	939.0	1.64332E 10	7.87823E 09	2.49890E 10	4.93004E 10	.316	3910.3	15748.3
.040	932.2	1.64332E 10	7.82185E 09	2.46326E 10	4.88876E 10	.423	3877.5	20984.6
.055	922.2	1.64332E 10	7.73739E 09	2.41035E 10	4.82741E 10	.585	3828.9	28827.3
.065	915.4	1.64332E 10	7.68117E 09	2.37545E 10	4.78689E 10	.694	3796.7	34048.2
.080	905.4	1.64332E 10	7.59696E 09	2.32365E 10	4.72667E 10	.858	3749.0	41868.8
.090	898.7	1.64332E 10	7.54089E 09	2.28948E 10	4.68689E 10	.969	3717.4	47075.7
.105	888.7	1.64332E 10	7.45690E 09	2.23876E 10	4.62777E 10	1.137	3670.5	54876.1
.115	882.0	1.64332E 10	7.40097E 09	2.20531E 10	4.58872E 10	1.250	3639.6	60070.1
.127	874.0	1.64332E 10	7.32555E 09	2.16059E 10	4.53646E 10	1.387	3598.1	67334.0

.127 874.8 = EXPERIMENTAL VALUES SPEED DEVIANT IS -.8 RELATIVE SPEED ERROR IS -.001

	TBHN	THICK	PMASS	ANG	VSP	VRE	RMASS	PDIA	HDIA	TRHO
INPUT IS	190.0	.127	7.780	.0	959.2	874.8	7.720	1.267	.000	4.48

TITANIUM ALLOY

DATUM SET NR. 19 IDENTIFIER = 19.0

X (CM)	VR (M/S)	F(V0) (DYNES)	F(V1) (DYNES)	F(V2) (DYNES)	FORCE (DYNES)	TIME (MU-SEC)	PRESSURE (M PA)	IMPULSE (DYNE-SEC)
.000	976.0	1.64332E 10	8.17403E 09	2.69007E 10	5.15079E 10	.000	4085.4	.0
.005	972.6	1.64332E 10	8.15933E 09	2.68074E 10	5.14004E 10	.051	4076.8	2637.9
.035	952.3	1.64332E 10	7.98990E 09	2.57018E 10	5.01248E 10	.363	3975.7	18427.2
.065	932.1	1.64332E 10	7.82043E 09	2.46237E 10	4.88773E 10	.681	3876.7	34155.1
.100	918.6	1.64332E 10	7.62361E 09	2.33998E 10	4.74566E 10	1.062	3764.0	52433.4
.130	888.5	1.64332E 10	7.45550E 09	2.23792E 10	4.62679E 10	1.396	3669.8	68065.7
.160	868.5	1.64332E 10	7.28787E 09	2.13642E 10	4.51053E 10	1.737	3577.5	83613.4
.195	845.2	1.64332E 10	7.09283E 09	2.02549E 10	4.37810E 10	2.146	3472.5	101727.3
.225	825.3	1.64332E 10	6.92604E 09	1.93135E 10	4.26727E 10	2.505	3384.6	117219.3
.255	805.4	1.64332E 10	6.75951E 09	1.83959E 10	4.15886E 10	2.873	3298.6	132686.6
.290	782.3	1.64332E 10	6.56546E 09	1.73549E 10	4.03536E 10	3.314	3200.7	150710.6
.318	763.7	1.64332E 10	6.40479E 09	1.65158E 10	3.93535E 10	3.676	3121.4	166665.0

.318 785.5 = EXPERIMENTAL VALUES SPEED DEVIANT IS -21.7 RELATIVE SPEED ERROR IS -.028

	TBHN	THICK	PMASS	ANG	VSP	VRE	RMASS	PDIA	HDIA	TRHO
INPUT IS	190.0	.318	7.780	.0	976.0	785.5	7.720	1.267	.000	4.48

DATUM SET NR. 20 IDENTIFIER = 20.0

X (CM)	VR (M/S)	F(V0) (DYNES)	F(V1) (DYNES)	F(V2) (DYNES)	FORCE (DYNES)	TIME (MU-SEC)	PRESSURE (M PA)	IMPULSE (DYNE-SEC)
.000	1484.4	1.64332E 10	1.24321E 10	6.22274E 10	9.10926E 10	.000	7225.0	.0
.003	1472.4	1.64332E 10	1.24239E 10	6.21447E 10	9.10017E 10	.017	7217.8	1533.7
.065	1433.5	1.64332E 10	1.20145E 10	5.81169E 10	8.65646E 10	.446	6865.9	39547.4
.126	1385.5	1.64332E 10	1.16117E 10	5.42858E 10	8.23307E 10	.889	6530.1	76948.0
.193	1336.3	1.64332E 10	1.11996E 10	5.05005E 10	7.81332E 10	1.367	6197.2	115222.7
.255	1289.7	1.64332E 10	1.08034E 10	4.70431E 10	7.42857E 10	1.843	5892.0	151455.5
.318	1243.5	1.64332E 10	1.04250E 10	4.37563E 10	7.06144E 10	2.336	5600.8	187157.9
.383	1196.8	1.64332E 10	1.00309E 10	4.05105E 10	6.69746E 10	2.869	5312.1	223756.7
.445	1152.2	1.64332E 10	9.65710E 09	3.75478E 10	6.36381E 10	3.401	5047.5	258467.4
.510	1106.4	1.64332E 10	9.27340E 09	3.46234E 10	6.03300E 10	3.977	4785.1	294101.0
.573	1062.8	1.64332E 10	8.90892E 09	3.19552E 10	5.72973E 10	4.553	4544.6	327950.4
.635	1019.5	1.64332E 10	8.54844E 09	2.94215E 10	5.44031E 10	5.154	4315.0	362762.3

.635 994.9 = EXPERIMENTAL VALUES SPEED DEVIANT IS 24.9 RELATIVE SPEED ERROR IS .025

	TBHN	THICK	PMASS	ANG	VSP	VRE	RMASS	PDIA	HDIA	TRHO
INPUT IS	190.0	.635	7.780	.0	1484.4	994.9	-10.000	1.267	.000	4.48

RHA

DATUM SET NR. 1 IDENTIFIER = 1.0

X (CM)	VR (M/S)	F(V0) (DYNES)	F(V1) (DYNES)	F(V2) (DYNES)	FORCE (DYNES)	TIME (MU-SEC)	PRESSURE (M PA)	IMPULSE (DYNE-SEC)
.000	888.5	4.19017E 09	2.96636E 09	1.38940E 10	2.10506E 10	.000	4652.5	.0
.001	887.1	4.19017E 09	2.96403E 09	1.38722E 10	2.10264E 10	.013	4647.2	272.4
.005	882.9	4.19017E 09	2.95005E 09	1.37417E 10	2.08819E 10	.052	4615.3	1088.3
.009	877.3	4.19017E 09	2.93147E 09	1.35691E 10	2.06907E 10	.104	4573.0	2173.4
.014	871.8	4.19017E 09	2.91293E 09	1.33981E 10	2.05012E 10	.157	4531.1	3255.5
.018	866.3	4.19017E 09	2.89445E 09	1.32286E 10	2.03132E 10	.210	4489.6	4334.4
.023	860.7	4.19017E 09	2.87603E 09	1.30607E 10	2.01269E 10	.263	4448.4	5410.3
.028	855.2	4.19017E 09	2.85765E 09	1.28943E 10	1.99422E 10	.317	4407.6	6483.2
.032	849.8	4.19017E 09	2.83933E 09	1.27295E 10	1.97590E 10	.371	4367.1	7553.1
.037	844.3	4.19017E 09	2.82105E 09	1.25662E 10	1.95774E 10	.425	4327.0	8620.0
.041	838.8	4.19017E 09	2.80253E 09	1.24044E 10	1.93974E 10	.480	4287.2	9683.9
.046	833.4	4.19017E 09	2.78466E 09	1.22440E 10	1.92189E 10	.535	4247.7	10745.0
.046	833.4	4.19017E 09	2.78239E 09	1.22241E 10	1.91967E 10	.535	4242.8	10765.0

.046 848.9 = EXPERIMENTAL VALUES SPEED DEVIANT IS -15.5 RELATIVE SPEED ERROR IS -.018

	TBHN	THICK	PMASS	ANG	VSP	VRE	RMASS	PDIA	HDIA	TRHO
INPUT IS	135.0	.046	1.950	.0	888.5	848.9	-10.000	.759	.000	7.78

DATUM SET NR. 2 IDENTIFIER = 2.0

X (CM)	VR (M/S)	F(V0) (DYNES)	F(V1) (DYNES)	F(V2) (DYNES)	FORCE (DYNES)	TIME (MU-SEC)	PRESSURE (M PA)	IMPULSE (DYNE-SEC)
.000	1211.6	4.19017E 09	4.04504E 09	2.58361E 10	3.40713E 10	.000	7530.4	.0
.001	1209.8	4.19017E 09	4.04203E 09	2.57977E 10	3.40299E 10	.010	7521.2	331.4
.016	1188.3	4.19017E 09	3.97025E 09	2.48896E 10	3.30500E 10	.135	7304.6	4341.5
.031	1167.0	4.19017E 09	3.89928E 09	2.40076E 10	3.20971E 10	.263	7094.0	8685.4
.046	1146.0	4.19017E 09	3.82909E 09	2.31511E 10	3.11704E 10	.393	6889.2	12783.0
.061	1125.2	4.19017E 09	3.75968E 09	2.23194E 10	3.02692E 10	.525	6690.0	16835.3
.076	1104.7	4.19017E 09	3.69102E 09	2.15117E 10	2.93929E 10	.659	6496.3	20843.4
.091	1084.4	4.19017E 09	3.62311E 09	2.07274E 10	2.85407E 10	.796	6308.0	24808.0
.108	1062.6	4.19017E 09	3.55036E 09	1.99034E 10	2.76439E 10	.948	6109.8	29055.0
.123	1042.7	4.19017E 09	3.48396E 09	1.91658E 10	2.68399E 10	1.090	5932.1	32932.0
.138	1023.0	4.19017E 09	3.41825E 09	1.84497E 10	2.60581E 10	1.235	5759.3	36768.1
.152	1004.2	4.19017E 09	3.35430E 09	1.77658E 10	2.53103E 10	1.378	5594.0	40627.3

.152 1015.0 = EXPERIMENTAL VALUES SPEED DEVIANT IS -10.8 RELATIVE SPEED ERROR IS -.011

	TBHN	THICK	PMASS	ANG	VSP	VRE	RMASS	PDIA	HDIA	TRHO
INPUT IS	135.0	.152	1.950	.0	1211.6	1015.0	-10.000	.759	.000	7.78

SAMPLE OUTPUT FOR Z/F FORCE PENETRATION MODEL PREDICTING RESIDUAL VELOCITY

RHA

DATUM SET NR. 3 IDENTIFIER = 3.0

X (CM)	VR (M/S)	F(V0) (DYNES)	F(V1) (DYNES)	F(V2) (DYNES)	FORCE (DYNES)	TIME (MU-SEC)	PRESSURE (M PA)	IMPULSE (DYNE-SEC)
.000	1521.3	9.31146E 09	7.57126E 09	4.07315E 10	5.76142E 10	.000	12733.7	.0
.001	1518.8	9.31146E 09	7.56522E 09	4.06665E 10	5.75432E 10	.008	12718.1	473.2
.033	1458.8	9.31146E 09	7.26652E 09	3.75186E 10	5.40966E 10	.218	11956.3	12171.6
.064	1400.1	9.31146E 09	6.97408E 09	3.45595E 10	5.08450E 10	.437	11237.6	23624.4
.096	1340.3	9.31146E 09	6.67627E 09	3.16709E 10	4.76587E 10	.674	10533.4	35288.4
128	1283.9	9.31146E 09	6.39566E 09	2.90646E 10	4.47718E 10	.912	9895.3	46278.2
.160	1226.5	9.31146E 09	6.10949E 09	2.65218E 10	4.19428E 10	1.171	9270.1	57486.6
.191	1172.2	9.31146E 09	5.83940E 09	2.42287E 10	3.93796E 10	1.432	8703.6	68064.7
.224	1116.5	9.31146E 09	5.56344E 09	2.19928E 10	3.68678E 10	1.716	8148.4	78873.3
.255	1064.4	9.31146E 09	5.30247E 09	1.99779E 10	3.45918E 10	2.003	7645.4	89095.4
.286	1012.7	9.31146E 09	5.04538E 09	1.80876E 10	3.24445E 10	2.304	7170.8	99165.1
.318	961.0	9.31146E 09	4.78474E 09	1.62671E 10	3.03633E 10	2.625	6710.8	109416.2

.318 1196.3 = EXPERIMENTAL VALUES SPEED DEVIANT IS -235.4 RELATIVE SPEED ERROR IS -.197

	TBHN	THICK	PMASS	ANG	VSP	VRE	RMASS	PDIA	HDIA	TRHO
INPUT IS	300.0	.318	1.950	.0	1521.3	1196.3	-10.000	.759	.000	7.78

DATUM SET NR. 4 IDENTIFIER = 4.0

X (CM)	VR (M/S)	F(V0) (DYNES)	F(V1) (DYNES)	F(V2) (DYNES)	FORCE (DYNES)	TIME (MU-SEC)	PRESSURE (M PA)	IMPULSE (DYNE-SEC)
.000	1394.5	9.46667E 09	6.99778E 09	3.42243E 10	5.06888E 10	.000	11203.1	.0
.001	1392.1	9.46667E 09	6.99193E 09	3.41672E 10	5.06258E 10	.009	11189.2	454.2
.064	1278.0	9.46667E 09	6.41900E 09	2.87972E 10	4.46829E 10	.478	9875.7	22708.3
.128	1168.0	9.46667E 09	5.85650E 09	2.39713E 10	3.92945E 10	1.000	8684.8	44558.1
.191	1057.7	9.46667E 09	5.31321E 09	1.97301E 10	3.45099E 10	1.574	7627.3	65662.8
.255	952.7	9.46667E 09	4.73587E 09	1.60080E 10	3.02605E 10	2.209	6688.1	86168.6
.318	852.0	9.46667E 09	4.28071E 09	1.28070E 10	2.65544E 10	2.902	5869.0	105774.3
.381	750.8	9.46667E 09	3.77288E 09	9.94858E 09	2.31891E 10	3.699	5125.0	125505.9
.445	649.9	9.46667E 09	3.25621E 09	7.45595E 09	2.01899E 10	4.610	4462.1	145195.2
.509	547.2	9.46667E 09	2.75112E 09	5.28972E 09	1.75075E 10	5.678	3869.5	165216.4
.572	440.6	9.46667E 09	2.21361E 09	3.42467E 09	1.51050E 10	6.959	3338.5	186010.0
.635	321.8	9.46667E 09	1.61431E 09	1.62245E 09	1.29039E 10	8.622	2852.0	209171.4

.635 460.3 = EXPERIMENTAL VALUES SPEED DEVIANT IS -138.5 RELATIVE SPEED ERROR IS -.301

	TBHN	THICK	PMASS	ANG	VSP	VRE	RMASS	PDIA	HDIA	TRHO
INPUT IS	375.0	.635	1.950	.0	1394.5	460.3	-10.000	.759	.000	7.78

SAMPLE OUTPUT FOR Z/F FORCE PENETRATION MODEL PREDICTING RESIDUAL VELOCITY

RHA

DATUM SET NR. 5 IDENTIFIER = 5.0

X (CM)	VR (M/S)	F(V0) (DYNES)	F(V1) (DYNES)	F(V2) (DYNES)	FORCE (DYNES)	TIME (MU-SEC)	PRESSURE (M PA)	IMPULSE (DYNE-SEC)
.000	609.9	1.21980E 10	3.47423E 09	6.54697E 09	2.22192E 10	.000	4910.8	.0
.001	607.6	1.21980E 10	3.46758E 09	6.52191E 09	2.21676E 10	.021	4903.8	455.6
.016	580.5	1.21980E 10	3.31023E 09	5.94344E 09	2.14517E 10	.263	4741.2	5729.6
.031	551.9	1.21980E 10	3.14724E 09	5.37256E 09	2.07178E 10	.528	4579.0	11311.0
.046	522.8	1.21980E 10	2.98141E 09	4.82131E 09	2.00008E 10	.807	4420.5	16989.9
.061	492.4	1.21980E 10	2.80674E 09	4.27295E 09	1.92777E 10	1.108	4260.7	22910.8
.076	461.3	1.21980E 10	2.62932E 09	3.74980E 09	1.85772E 10	1.430	4105.9	28986.9
.091	429.8	1.21980E 10	2.45005E 09	3.25591E 09	1.79040E 10	1.766	3957.1	35125.0
.107	396.4	1.21980E 10	2.26000E 09	2.77038E 09	1.72284E 10	2.137	3807.8	41633.7
.122	361.8	1.21980E 10	2.06178E 09	2.30572E 09	1.65655E 10	2.537	3661.3	48387.2
.137	325.0	1.21980E 10	1.85252E 09	1.86144E 09	1.59120E 10	2.979	3516.8	55552.9
.152	285.4	1.21980E 10	1.62618E 09	1.43437E 09	1.52586E 10	3.474	3372.4	63300.4

.152 367.9 = EXPERIMENTAL VALUES SPEED DEVIANT IS -82.5 RELATIVE SPEED ERROR IS -.224

	TBHN	THICK	PMASS	ANG	VSP	VRE	RMASS	PDIA	HDIA	TRHO
INPUT IS	393.0	.152	1.950	.0	609.9	367.9	-10.000	.759	.000	7.78

DATUM SET NR. 6 IDENTIFIER = 6.0

X (CM)	VR (M/S)	F(V0) (DYNES)	F(V1) (DYNES)	F(V2) (DYNES)	FORCE (DYNES)	TIME (MU-SEC)	PRESSURE (M PA)	IMPULSE (DYNE-SEC)
.000	302.1	7.46391E 09	1.79639E 09	2.86052E 09	1.21208E 10	.000	1503.9	.0
.001	301.5	7.46391E 09	1.79462E 09	2.85490E 09	1.21134E 10	.019	1503.0	230.8
.005	297.3	7.46391E 09	1.76985E 09	2.77665E 09	1.20104E 10	.153	1490.2	1851.9
.009	292.5	7.46391E 09	1.74138E 09	2.68803E 09	1.18933E 10	.309	1475.7	3714.6
.014	287.7	7.46391E 09	1.71272E 09	2.60027E 09	1.17769E 10	.468	1461.2	5590.1
.018	282.8	7.46391E 09	1.68386E 09	2.51338E 09	1.16612E 10	.629	1446.9	7478.7
.023	277.9	7.46391E 09	1.65479E 09	2.42734E 09	1.15461E 10	.793	1432.6	9381.1
.028	273.0	7.46391E 09	1.62457E 09	2.33951E 09	1.14280E 10	.960	1418.0	11298.3
.032	268.0	7.46391E 09	1.59503E 09	2.25519E 09	1.13141E 10	1.130	1403.8	13231.2
.037	263.0	7.46391E 09	1.56523E 09	2.17172E 09	1.12009E 10	1.304	1389.8	15180.8
.041	258.0	7.46391E 09	1.53517E 09	2.08909E 09	1.10882E 10	1.480	1375.8	17148.0
.046	252.9	7.46391E 09	1.50481E 09	2.00729E 09	1.09760E 10	1.660	1361.9	19134.2
.046	252.9	7.46391E 09	1.50481E 09	2.00729E 09	1.09760E 10	1.660	1361.9	19256.9

.046 277.4 = EXPERIMENTAL VALUES SPEED DEVIANT IS -24.5 RELATIVE SPEED ERROR IS -.088

	TBHN	THICK	PMASS	ANG	VSP	VRE	RMASS	PDIA	HDIA	TRHO
INPUT IS	135.0	.046	3.890	.0	302.1	277.4	-10.000	1.013	.000	7.78

SAMPLE OUTPUT FOR Z/F FORCE PENETRATION MODEL PREDICTING RESIDUAL VELOCITY

RHA

DATUM SET NR. 7 IDENTIFIER = 7.0

X (CM)	VR (M/S)	F(V0) (DYNES)	F(V1) (DYNES)	F(V2) (DYNES)	FORCE (DYNES)	TIME (MU-SEC)	PRESSURE (M PA)	IMPULSE (DYNE-SEC)
.000	393.5	7.46391E 09	2.34019E 09	4.85454E 09	1.46586E 10	.000	1818.8	.0
.001	392.3	7.46391E 09	2.33663E 09	4.83978E 09	1.46403E 10	.032	1816.5	465.8
.016	377.9	7.46391E 09	2.25088E 09	4.49107E 09	1.42059E 10	.421	1762.6	6076.5
.031	363.3	7.46391E 09	2.16444E 09	4.15274E 09	1.37811E 10	.826	1709.9	11732.7
.046	348.7	7.46391E 09	2.07715E 09	3.82458E 09	1.33657E 10	1.248	1658.4	17444.3
.061	333.8	7.46391E 09	1.98701E 09	3.49982E 09	1.29508E 10	1.687	1606.9	23222.5
.076	318.7	7.46391E 09	1.89747E 09	3.19152E 09	1.25529E 10	2.147	1557.5	29080.9
.091	303.4	7.46391E 09	1.80647E 09	2.89274E 09	1.21631E 10	2.629	1509.2	35035.5
.107	287.2	7.46391E 09	1.70980E 09	2.59142E 09	1.17651E 10	3.158	1459.8	41361.3
.122	271.2	7.46391E 09	1.61382E 09	2.30864E 09	1.13864E 10	3.696	1412.8	47577.3
.137	254.8	7.46391E 09	1.51620E 09	2.03780E 09	1.10179E 10	4.266	1367.1	53964.3
.152	237.7	7.46391E 09	1.41389E 09	1.77204E 09	1.06498E 10	4.881	1321.4	60673.4

.152 256.0 = EXPERIMENTAL VALUES SPEED DEVIANT IS -18.4 RELATIVE SPEED ERROR IS -.072

	TBHN	THICK	PMASS	ANG	VSP	VRE	RMASS	PDIA	HDIA	TRHO
INPUT IS	135.0	.152	3.890	.0	393.5	256.0	-10.000	1.013	.000	7.78

DATUM SET NR. 8 IDENTIFIER = 8.0

X (CM)	VR (M/S)	F(V0) (DYNES)	F(V1) (DYNES)	F(V2) (DYNES)	FORCE (DYNES)	TIME (MU-SEC)	PRESSURE (M PA)	IMPULSE (DYNE-SEC)
.000	883.6	7.46391E 09	5.25499E 09	2.44788E 10	3.71977E 10	.000	4615.4	.0
.001	882.3	7.46391E 09	5.25097E 09	2.44413E 10	3.71562E 10	.014	4610.2	526.0
.033	848.8	7.46391E 09	5.05165E 09	2.26210E 10	3.51366E 10	.375	4359.6	13559.2
.064	815.8	7.46391E 09	4.85566E 09	2.08998E 10	3.32194E 10	.751	4121.8	26374.4
.096	782.1	7.46391E 09	4.65517E 09	1.92095E 10	3.13286E 10	1.158	3887.2	39484.4
.128	750.2	7.46391E 09	4.46539E 09	1.76752E 10	2.96045E 10	1.566	3673.2	51893.8
.160	717.5	7.46391E 09	4.27093E 09	1.61693E 10	2.79041E 10	2.009	3462.3	64610.0
.191	686.5	7.46391E 09	4.08652E 09	1.48031E 10	2.63535E 10	2.454	3269.9	76669.3
.224	654.7	7.46391E 09	3.89715E 09	1.34629E 10	2.48240E 10	2.939	3080.1	89052.9
.255	624.4	7.46391E 09	3.71714E 09	1.22479E 10	2.34290E 10	3.427	2907.0	100825.0
.286	594.5	7.46391E 09	3.53889E 09	1.11014E 10	2.21042E 10	3.940	2742.6	112482.3
.318	564.3	7.46391E 09	3.35716E 09	9.99058E 09	2.08117E 10	4.488	2582.2	124413.1

.318 542.5 = EXPERIMENTAL VALUES SPEED DEVIANT IS 21.7 RELATIVE SPEED ERROR IS .040

	TBHN	THICK	PMASS	ANG	VSP	VRE	RMASS	PDIA	HDIA	TRHO
INPUT IS	135.0	.318	3.890	.0	883.6	542.5	-10.000	1.013	.000	7.78

SAMPLE OUTPUT FOR Z/F FORCE PENETRATION MODEL PREDICTING RESIDUAL VELOCITY

RHA

DATUM SET NR. 9 IDENTIFIER = 9.0

X (CM)	VR (M/S)	F(V0) (DYNES)	F(V1) (DYNES)	F(V2) (DYNES)	FORCE (DYNES)	TIME (MU-SEC)	PRESSURE (M PA)	IMPULSE (DYNE-SEC)
.000	879.6	1.65865E 10	7.79848E 09	2.42593E 10	4.86443E 10	.000	6035.6	.0
.003	876.1	1.65865E 10	7.78273E 09	2.41614E 10	4.85307E 10	.028	6021.5	1382.1
.033	833.6	1.65865E 10	7.40609E 09	2.18794E 10	4.58721E 10	.379	5691.7	17904.0
.065	787.9	1.65865E 10	7.00050E 09	1.95486E 10	4.31357E 10	.780	5352.1	35696.8
.098	742.3	1.65865E 10	6.59651E 09	1.73575E 10	4.05405E 10	1.205	5030.1	53421.6
.128	700.3	1.65865E 10	6.22402E 09	1.54525E 10	3.82631E 10	1.621	4747.6	69765.9
.160	654.7	1.65865E 10	5.81969E 09	1.35101E 10	3.59163E 10	2.101	4456.4	87510.0
.193	608.8	1.65865E 10	5.41290E 09	1.16874E 10	3.36869E 10	2.616	4179.8	105364.9
.224	564.2	1.65865E 10	5.00954E 09	1.00105E 10	3.16065E 10	3.149	3921.6	122723.3
.255	518.8	1.65865E 10	4.60739E 09	8.46775E 09	2.96617E 10	3.726	3680.3	140376.2
.286	472.3	1.65865E 10	4.19113E 09	7.00681E 09	2.77844E 10	4.357	3447.4	158460.0
.318	423.3	1.65865E 10	3.75648E 09	5.62885E 09	2.59718E 10	5.067	3222.5	177815.8

.316 583.7 = EXPERIMENTAL VALUES SPEED DEVIANT IS -160.4 RELATIVE SPEED ERROR IS -.275

	TBHN	THICK	PMASS	ANG	VSP	VRE	RMASS	PDIA	HDIA	TRHO
INPUT IS	300.0	.318	3.890	.0	879.6	583.7	-10.000	1.013	.000	7.78

DATUM SET NR. 10 IDENTIFIER = 10.0

X (CM)	VR (M/S)	F(V0) (DYNES)	F(V1) (DYNES)	F(V2) (DYNES)	FORCE (DYNES)	TIME (MU-SEC)	PRESSURE (M PA)	IMPULSE (DYNE-SEC)
.000	1466.1	1.65865E 10	1.29975E 10	6.73875E 10	9.69715E 10	.000	12031.9	.0
.001	1464.0	1.65865E 10	1.29881E 10	6.72899E 10	9.68645E 10	.009	12018.7	826.5
.033	1411.4	1.65865E 10	1.25216E 10	6.25431E 10	9.16512E 10	.226	11371.8	21287.4
.064	1359.7	1.65865E 10	1.20637E 10	5.80522E 10	8.67023E 10	.452	10757.8	41373.4
.096	1307.0	1.65865E 10	1.15961E 10	5.36391E 10	8.18217E 10	.695	10152.2	61883.4
.128	1257.2	1.65865E 10	1.11544E 10	4.96307E 10	7.73713E 10	.939	9600.0	81237.9
.160	1206.3	1.65865E 10	1.07028E 10	4.56934E 10	7.29827E 10	1.203	9055.5	101066.2
.191	1158.1	1.65865E 10	1.02756E 10	4.21188E 10	6.89809E 10	1.467	8558.9	119803.7
.224	1108.8	1.65865E 10	9.83824E 09	3.86094E 10	6.50341E 10	1.754	8069.2	138990.3
.255	1062.1	1.65865E 10	9.42379E 09	3.54249E 10	6.14352E 10	2.042	7622.7	157170.8
.286	1015.9	1.65865E 10	9.01484E 09	3.24171E 10	5.80184E 10	2.343	7198.8	175109.9
.318	969.7	1.65865E 10	8.59965E 09	2.94998E 10	5.46850E 10	2.663	6785.3	193394.2

.318 1164.3 = EXPERIMENTAL VALUES SPEED DEVIANT IS -194.7 RELATIVE SPEED ERROR IS -.167

	TBHN	THICK	PMASS	ANG	VSP	VRE	RMASS	PDIA	HDIA	TRHO
INPUT IS	300.0	.318	3.890	.0	1466.1	1164.3	-10.000	1.013	.000	7.78

SAMPLE OUTPUT FOR Z/F FORCE PENETRATION MODEL PREDICTING RESIDUAL VELOCITY

RHA

DATUM SET NR. 11 IDENTIFIER = 11.0

X (CM)	VR (M/S)	F(V0) (DYNES)	F(V1) (DYNES)	F(V2) (DYNES)	FORCE (DYNES)	TIME (MU-SEC)	PRESSURE (M PA)	IMPULSE (DYNE-SEC)
.000	1466.1	1.65865E 10	1.29975E 10	6.73875E 10	9.69715E 10	.000	12031.9	.0
.001	1464.0	1.65865E 10	1.29881E 10	6.72899E 10	9.68645E 10	.009	12018.7	826.5
.064	1359.7	1.65865E 10	1.20637E 10	5.80522E 10	8.67023E 10	.452	10757.8	41373.4
.128	1257.2	1.65865E 10	1.11544E 10	4.96307E 10	7.73715E 10	.939	9600.0	81257.9
.191	1158.1	1.65865E 10	1.02756E 10	4.21188E 10	6.89809E 10	1.467	8558.9	119803.7
.255	1062.1	1.65865E 10	9.42379E 09	3.54249E 10	6.14352E 10	2.042	7622.7	157170.8
.318	970.4	1.65865E 10	8.61089E 09	2.95770E 10	5.47744E 10	2.658	6796.2	192850.4
.381	878.9	1.65865E 10	7.79995E 09	2.42684E 10	4.86549E 10	3.348	6036.9	228406.5
.445	788.9	1.65865E 10	7.00195E 09	1.95567E 10	4.31452E 10	4.113	5353.3	263417.1
.509	699.6	1.65865E 10	6.20994E 09	1.53827E 10	3.81791E 10	4.971	4737.2	298168.3
.573	609.8	1.65865E 10	5.41436E 09	1.16937E 10	3.36946E 10	5.946	4180.7	333080.8
.635	519.9	1.65865E 10	4.61703E 09	8.50323E 09	2.97068E 10	7.054	3685.9	368791.2

.635 687.3 = EXPERIMENTAL VALUES SPEED DEVIANT IS -167.4 RELATIVE SPEED ERROR IS -.244

	TBHN	THICK	PMASS	ANG	VSP	VRE	RMASS	PDIA	HDIA	TRHO
INPUT IS	300.0	.635	3.890	.0	1466.1	687.3	-10.000	1.013	.000	7.78

DATUM SET NR. 12 IDENTIFIER = 12.0

X (CM)	VR (M/S)	F(V0) (DYNES)	F(V1) (DYNES)	F(V2) (DYNES)	FORCE (DYNES)	TIME (MU-SEC)	PRESSURE (M PA)	IMPULSE (DYNE-SEC)
.000	909.5	2.59471E 10	1.26138E 10	4.05711E 10	7.91320E 10	.000	6276.4	.0
.003	906.7	2.59471E 10	1.25944E 10	4.04466E 10	7.89881E 10	.028	6265.0	2174.5
.033	873.3	2.59471E 10	1.21308E 10	3.75234E 10	7.56013E 10	.365	5996.3	28177.3
.065	837.3	2.59471E 10	1.16315E 10	3.44983E 10	7.20770E 10	.745	5716.8	56178.6
.098	801.5	2.59471E 10	1.11348E 10	3.16146E 10	6.86966E 10	1.141	5448.7	84039.8
.128	768.6	2.59471E 10	1.06779E 10	2.90733E 10	6.56984E 10	1.524	5210.9	109668.1
.160	732.9	2.59471E 10	1.01839E 10	2.64457E 10	6.25768E 10	1.957	4963.3	137376.6
.193	697.3	2.59471E 10	9.69015E 09	2.39433E 10	5.95807E 10	2.411	4725.7	165077.2
.225	661.7	2.59471E 10	9.19551E 09	2.15613E 10	5.67040E 10	2.890	4497.5	192828.6
.255	628.6	2.59471E 10	8.73710E 09	1.94652E 10	5.41495E 10	3.355	4294.9	218549.9
.288	592.5	2.59471E 10	8.23715E 09	1.73013E 10	5.14856E 10	3.887	4083.6	246604.6
.318	558.4	2.59471E 10	7.74768E 09	1.53062E 10	4.90010E 10	4.417	3886.5	273637.3

.318 690.4 = EXPERIMENTAL VALUES SPEED DEVIANT IS -132.0 RELATIVE SPEED ERROR IS -.191

	TBHN	THICK	PMASS	ANG	VSP	VRE	RMASS	PDIA	HDIA	TRHO
INPUT IS	300.0	.318	7.780	.0	909.5	690.4	-10.000	1.267	.000	7.78

SAMPLE OUTPUT FOR Z/F FORCE PENETRATION MODEL PREDICTING RESIDUAL VELOCITY

RHA

DATUM SET NR. 13 IDENTIFIER = 13.0

X (CM)	VR (M/S)	F(V0) (DYNES)	F(V1) (DYNES)	F(V2) (DYNES)	FORCE (DYNES)	TIME (MU-SEC)	PRESSURE (M PA)	IMPULSE (DYNE-SEC)
.000	916.5	3.59328E 10	1.76029E 10	5.70543E 10	1.10590E 11	.000	6333.9	.0
.005	912.7	3.59328E 10	1.75656E 10	5.68133E 10	1.10312E 11	.055	6318.0	6030.7
.035	889.5	3.59328E 10	1.71201E 10	5.39675E 10	1.07020E 11	.388	6129.5	42116.4
.065	866.4	3.59328E 10	1.66764E 10	5.12067E 10	1.03816E 11	.729	5965.9	78066.1
.100	839.5	3.59328E 10	1.61610E 10	4.80904E 10	1.00184E 11	1.140	5737.9	119790.3
.130	816.6	3.59328E 10	1.57208E 10	4.55064E 10	9.71601E 10	1.502	5564.7	155443.7
.160	793.8	3.59328E 10	1.52818E 10	4.30005E 10	9.42152E 10	1.875	5396.1	191000.9
.195	767.2	3.59328E 10	1.47709E 10	4.01730E 10	9.08768E 10	2.323	5204.8	232391.8
.225	744.4	3.59328E 10	1.43336E 10	3.78295E 10	8.80960E 10	2.720	5045.6	267817.6
.255	721.7	3.59328E 10	1.38965E 10	3.55578E 10	8.53874E 10	3.129	4890.4	303222.6
.290	695.1	3.59328E 10	1.33866E 10	3.29960E 10	8.23156E 10	3.624	4714.5	344960.2
.318	673.8	3.59328E 10	1.29635E 10	3.09435E 10	7.98399E 10	4.033	4572.7	381183.8

.318 754.4 = EXPERIMENTAL VALUES SPEED DEVIANT IS -80.5 RELATIVE SPEED ERROR IS -.107

	TBHN	THICK	PMASS	ANG	VSP	VRE	RMASS	PDIA	HDIA	TRHO
INPUT IS	300.0	.318	15.560	.0	916.5	754.4	-10.000	1.491	.000	7.78

DATUM SET NR. 14 IDENTIFIER = 14.0

X (CM)	VR (M/S)	F(V0) (DYNES)	F(V1) (DYNES)	F(V2) (DYNES)	FORCE (DYNES)	TIME (MU-SEC)	PRESSURE (M PA)	IMPULSE (DYNE-SEC)
.000	1425.6	3.59328E 10	2.73791E 10	1.38026E 11	2.01337E 11	.000	11531.3	.0
.003	1423.3	3.59328E 10	2.73573E 10	1.37806E 11	2.01096E 11	.018	11517.5	3529.4
.033	1396.2	3.59328E 10	2.68370E 10	1.32614E 11	1.95384E 11	.230	11190.4	45662.5
.065	1367.2	3.59328E 10	2.62790E 10	1.27157E 11	1.89368E 11	.466	10865.8	90855.6
.098	1338.4	3.59328E 10	2.57266E 10	1.21867E 11	1.83526E 11	.706	10511.2	135591.3
.128	1312.1	3.59328E 10	2.52216E 10	1.17130E 11	1.78284E 11	.932	10211.0	176490.6
.160	1283.9	3.59328E 10	2.46796E 10	1.12150E 11	1.72762E 11	1.183	9894.7	220381.7
.193	1256.0	3.59328E 10	2.41429E 10	1.07325E 11	1.67400E 11	1.439	9587.6	263882.1
.225	1228.3	3.59328E 10	2.36111E 10	1.02649E 11	1.62193E 11	1.700	9289.4	306914.6
.255	1203.0	3.59328E 10	2.31247E 10	9.84629E 10	1.57520E 11	1.947	9021.8	346313.9
.288	1175.8	3.59328E 10	2.26022E 10	9.40638E 10	1.52599E 11	2.220	8739.9	388629.6
.318	1150.5	3.59328E 10	2.21001E 10	8.99314E 10	1.47964E 11	2.483	8474.5	428667.1

.318 1179.6 = EXPERIMENTAL VALUES SPEED DEVIANT IS -29.1 RELATIVE SPEED ERROR IS -.025

	TBHN	THICK	PMASS	ANG	VSP	VRE	RMASS	PDIA	HDIA	TRHO
INPUT IS	300.0	.318	15.560	.0	1425.6	1179.6	-10.000	1.491	.009	7.78

SAMPLE OUTPUT FOR Z/F FORCE PENETRATION MODEL PREDICTING RESIDUAL VELOCITY

RHA

DATUM SET NR. 15 IDENTIFIER = 15.0

X (CM)	VR (M/S)	F(VO) (DYNES)	F(V1) (DYNES)	F(V2) (DYNES)	FORCE (DYNES)	TIME (MU-SEC)	PRESSURE (M PA)	IMPULSE (DYNE-SEC)
.000	1432.6	3.59328E 10	2.75137E 10	1.39386E 11	2.02833E 11	.000	11617.0	.0
.003	1430.3	3.59328E 10	2.74919E 10	1.39165E 11	2.02590E 11	.017	11603.1	3538.3
.065	1374.0	3.59328E 10	2.64109E 10	1.28437E 11	1.90780E 11	.463	10926.7	91079.1
.128	1318.9	3.59328E 10	2.53510E 10	1.18335E 11	1.79618E 11	.928	10287.4	176918.1
.193	1262.6	3.59328E 10	2.42698E 10	1.08456E 11	1.68659E 11	1.431	9659.7	264480.1
.255	1209.5	3.59328E 10	2.32493E 10	9.95276E 10	1.58710E 11	1.937	9089.9	347123.0
.318	1157.3	3.59328E 10	2.22465E 10	9.11269E 10	1.49306E 11	2.465	8551.3	428339.7
.383	1103.9	3.59328E 10	2.12210E 10	8.29190E 10	1.40073E 11	3.040	8022.5	511396.9
.445	1053.4	3.59328E 10	2.02534E 10	7.55071E 10	1.31690E 11	3.620	7542.4	590011.5
.510	1001.6	3.59328E 10	1.92555E 10	6.82702E 10	1.23458E 11	4.253	7070.9	670591.5
.573	952.4	3.59328E 10	1.83114E 10	6.17398E 10	1.15984E 11	4.893	6642.8	747059.5
.635	903.9	3.59328E 10	1.73780E 10	5.56060E 10	1.08917E 11	5.566	6238.1	825673.6

.635 1037.8 = EXPERIMENTAL VALUES SPEED DEVIANT IS -134.0 RELATIVE SPEED ERROR IS -.129

	TBHN	THICK	PMASS	ANG	VSP	VRE	RMASS	PDIA	HDIA	YRHO
INPUT IS	300.0	.635	15.560	.0	1432.6	1037.8	-10.000	1.491	.000	7.78

DATUM SET NR. 16 IDENTIFIER = 16.0

X (CM)	VR (M/S)	F(VO) (DYNES)	F(V1) (DYNES)	F(V2) (DYNES)	FORCE (DYNES)	TIME (MU-SEC)	PRESSURE (M PA)	IMPULSE (DYNE-SEC)
.000	1556.0	3.65315E 10	3.01325E 10	1.64442E 11	2.31107E 11	.000	13236.3	.0
.003	1553.6	3.65315E 10	3.01094E 10	1.64190E 11	2.30831E 11	.016	13220.6	3711.6
.065	1494.6	3.65315E 10	2.89667E 10	1.51964E 11	2.17462E 11	.426	12454.8	93492.6
.128	1436.9	3.65315E 10	2.78474E 10	1.40447E 11	2.04826E 11	.853	11731.1	185392.4
.193	1378.0	3.65315E 10	2.67070E 10	1.29179E 11	1.92418E 11	1.315	11020.5	276985.2
.255	1322.5	3.65315E 10	2.56321E 10	1.18991E 11	1.81154E 11	1.778	10375.4	363315.6
.318	1268.1	3.65315E 10	2.45774E 10	1.09399E 11	1.70508E 11	2.260	9765.6	448030.8
.383	1212.5	3.65315E 10	2.35006E 10	1.00023E 11	1.60056E 11	2.784	9167.0	534519.6
.445	1160.0	3.65315E 10	2.24834E 10	9.15516E 10	1.50567E 11	3.311	8623.5	616226.9
.510	1106.3	3.65315E 10	2.14430E 10	8.32746E 10	1.41249E 11	3.885	8089.9	699796.8
.573	1055.4	3.65315E 10	2.04581E 10	7.58006E 10	1.32790E 11	4.464	7605.4	778908.5
.635	1005.3	3.65315E 10	1.94870E 10	6.87754E 10	1.24794E 11	5.070	7147.4	860013.2

.635 1109.5 = EXPERIMENTAL VALUES SPEED DEVIANT IS -134.2 RELATIVE SPEED ERROR IS -.094

	TBHN	THICK	PMASS	ANG	VSP	VRE	RMASS	PDIA	HDIA	YRHO
INPUT IS	305.0	.635	15.560	.0	1556.0	1109.5	-10.000	1.491	.000	7.78

SAMPLE OUTPUT FOR Z/F FORCE PENETRATION MODEL PREDICTING RESIDUAL VELOCITY

RHA

DATUM SET NR. 17 IDENTIFIER = 17.0

X (CM)	VR (M/S)	F(V0) (DYNES)	F(V1) (DYNES)	F(V2) (DYNES)	FORCE (DYNES)	TIME (MU-SEC)	PRESSURE (M PA)	IMPULSE (DYNE-SEC)
.000	1660.5	3.97655E 10	3.35503E 10	1.87283E 11	2.60599E 11	.000	14925.5	.0
.003	1658.0	3.97655E 10	3.35249E 10	1.86999E 11	2.60289E 11	.015	14907.7	3921.7
.128	1534.7	3.97655E 10	3.10319E 10	1.60222E 11	2.31019E 11	.799	13291.3	195832.3
.255	1414.0	3.97655E 10	2.85922E 10	1.36019E 11	2.04377E 11	1.664	11705.4	383649.3
.383	1297.9	3.97655E 10	2.62465E 10	1.14617E 11	1.80629E 11	2.605	10345.3	564225.2
.510	1186.0	3.97655E 10	2.39845E 10	9.57123E 10	1.59462E 11	3.633	9133.0	738371.1
.635	1079.8	3.97655E 10	2.18371E 10	7.93403E 10	1.40943E 11	4.737	8072.3	903704.7
.763	974.3	3.97655E 10	1.97057E 10	6.46086E 10	1.24080E 11	5.980	7106.5	1067805.[illegible]
.890	871.0	3.97655E 10	1.76192E 10	5.16507E 10	1.09036E 11	7.364	6244.9	1228470.7
1.018	769.1	3.97655E 10	1.55586E 10	4.02760E 10	9.56002E 10	8.921	5475.4	1387181.6
1.145	667.1	3.97655E 10	1.34985E 10	3.03161E 10	8.35803E 10	10.699	4786.9	1545820.8
1.270	565.3	3.97655E 10	1.14212E 10	2.17036E 10	7.28904E 10	12.731	4174.7	1706231.1

1.270 759.6 = EXPERIMENTAL VALUES SPEED DEVIANT IS -194.3 RELATIVE SPEED ERROR IS -.256

	TBHN	THICK	PMASS	ANG	VSP	VRE	RMASS	PDIA	HDIA	TRHO
INPUT IS	332.0	1.270	15.560	.0	1660.5	759.6	-10.000	1.491	.000	7.78

END OF RUN

```
C
C
C
COMM      PROGRAM USING  Z/F  EQUATION TO PREDICT RESIDUAL VELOCITY
C
C
C         GLOSSARY OF VARIABLES
C
C
C   ***          IDENTIFIES REQUIRED INPUT DATA
C     *          IDENTIFIES INPUT DATA WHICH IS NOT REQUIRED
C
C
C   ***   ANG    - THE ANGLE OF THE TARGET PLATE WITH RESPECT TO
C                    LINE OF FLIGHT  - OBLIQUITY  (DEGREES)
C         AREA   - THE PROJECTED CROSS-SECTIONAL AREA OF PROJECTILE
C                    ON IMPACT
C         C1     - CONSTANT BASED ON LEAST SQUARE FIT TO THOR DATA
C         C2     - CONSTANT BASED ON LEAST SQUARE FIT TO THOR DATA
C         C3     - CONSTANT BASED ON LEAST SQUARE FIT TO THOR DATA
C         D      - THE DEVIANT  = COMPUTED VALUE MINUS EXPERIMENTAL VALUE
C         DBAR   - THE AVERAGE (MEAN) VALUE OF THE DEVIANTS
C         DELTAX - ALLOWED TOLERANCE ON THE PLATE THICKNESS  (CM)
C         DELV   - THE INCREMENT ON THE RESIDUAL VELOCITY
C         DSD    - THE STANDARD DEVIATION OF THE DEVIANTS
C         DTOR   - CONVERSION FACTOR -  DEGREES TO RADIANS
C         DVAR   - THE VARIANCE OF THE DEVIANTS
C         EBAR   - THE AVERAGE (MEAN) VALUE OF THE RELATIVE ERROR
C         ESD    - THE STANDARD DEVIATION OF THE RELATIVE ERROR
C         EVAR   - THE VARIANCE OF THE RELATIVE ERROR
C     *   HDIA   - THE DIAMETER OF THE HOLE MADE IN THE TARGET  (CM)
C         ICT    - INDEX TO COUNT NUMBER OF DATA CARDS FOR ONE TARGET
C         ICTD   - INDEX COUNTER ON NUMBER OF POINTS FOR DEVIANTS
C         ICTE   - INDEX COUNTER ON NUMBER OF POINTS FOR RELATIVE ERROR
C     *   IDN    - AN IDENTIFICATION NUMBER OR SYMBOL-DESIGNATES SHOT NR.
C         IFLGM  - FLAG TO INDICATE RELATIONSHIP ON THICKNESS FOR THIS VR
C         IFLGP  - FLAG TO INDICATE RELATIONSHIP ON THICKNESS FOR THIS VR
C         IREP   - NUMBER OF ITERATIONS COUNTER INDEX
C   ***   PDIA   - DIAMETER OF THE PROJECTILE (CM)
C   ***   PMASS  - MASS OF PROJECTILE  (GRAMS)
C         RATIO  - USED TO DETERMINE A FIRST ESTIMATE OF RESIDUAL
C                    VELOCITY
C         RELERR - THE RELATIVE ERROR OF COMPUTED VS. EXPERIMENTAL
C     *   RMASS  - THE RECOVERED PROJECTILE MASS  (GRAMS)
C         SUMD   - THE SUM OF THE DEVIANTS
C         SUMDSQ - THE SUM OF THE DEVIANT  SQUARED
C         SUMRE  - THE SUM OF THE RELATIVE ERROR
```

```
C         SUMRES - THE SUM OF THE RELATIVE ERROR SQUARED
C   ***   TBHN   - THE TARGET BRINELL HARDNESS NUMBER  (KG/SQ MM)
C   ***   THICK  - THE THICKNESS OF THE TARGET PLATE  (CM)
C   ***   TRHO   - THE DENSITY OF THE TARGET PLATE  (G/CC)
C         VR     - PREDICTED RESIDUAL VELOCITY  (M/S)
C     *   VRE    - THE EXPERIMENTAL RESIDUAL VELOCITY  (M/S)
C   ***   VSP    - THE EXPERIMENTAL STRIKING VELOCITY  (M/S)
C         XT     - PREDICTED VALUE OF PLATE THICKNESS FOR CURRENT VALUE
C                    OF RESIDUAL VELOCITY
C         XTO    - VALUE OF PLATE THICKNESS WHEN VR=0  (MAX PENETRATION)
C
      DATA PI,DTOR / 3.141592654, 0.0174532925 /
   10 FORMAT( A6,2F6.1,F8.3,F5.1,2F6.3,2F8.1,2F7.2)
   12 FORMAT(10A6)
      C1=0.70
      C2=0.23
      C3=0.50
      DELTAX=0.001
  100 CONTINUE
      WRITE(6,103)
  103 FORMAT(1H1)
      WRITE(6,106)
  106 FORMAT(1H0,20X,42HSAMPLE OUTPUT FOR  Z/F EQUATION PREDICTING ,
     1   18H RESIDUAL VELOCITY  / )
C           READ CARD DESCRIBING THE TARGET MATERIAL
      READ(5,12)TGT1,TGT2,TGT3
      WRITE(6,12)TGT1,TGT2,TGT3
      WRITE(6,110)
  110 FORMAT(1H0,4X,39HNR  TRHO  TBHN   THICK  ANG  MASS  PDIA ,6X,
     1   2HVS,2X,12HRMASS   HDIA ,5X,3HVRE,6X,2HVR,5X,3HDEV,5X,
     2    3HSUM,8X,2HSQ,4X,4HR.E.,5X,3HSUM,6X,2HSQ )
      ICT=0
      ICTE=0
      ICTD=0
      SUMD=0.0
      SUMDSQ=0.0
      SUMRE=0.0
      SUMRES=0.0
C         ONE BLANK CARD USED TO SEPARATE DATA FOR DIFFERENT TARGETS
C         A CARD WITH  END  PUNCHED IN THE FIRST THREE COLUMNS
C         WILL TERMINATE THE PROGRAM
  150 READ(5,10)IDN,TRHO,TBHN,THICK,ANG,PMASS,PDIA,VSP,VRE,RMASS,HDIA
      IF(TRHO.LE.0.0)GOTO 200
C         COMPUTE PROJECTILE CROSS-SECTIONAL AREA
      AREA=PI*(PDIA/2.0)**2
C         THE UNIT OF VELOCITY TO BE USED IS CM/SEC
      VS=VSP*100.0
```

```
      VR=0.0
      DELV=10000.0
      THICKP=THICK+DELTAX
      THICKM=THICK-DELTAX
C        COMPUTE COEFFICIENTS AND OTHER QUANTITIES
C           (NOTE :  9.8E7  CONVERTS THE BRINELL HARDNESS NUMBER
C                    FROM  KG/MM**2  TO  DYNE/CM**2 )
      CA=9.8E7*TBHN*C1
      CB=SQRT(9.8E7*TBHN*TRHO)*C2
      CC=TRHO*C3
      QX=4.0*C1*C3-C2**2
      Q=QX*9.8E7*TBHN*TRHO
      Q0=SQRT(Q)
      Q1=CA+CB*VS+CC*VS**2
      Q3=2.0*CC*VS
      Q5=(COS(ANG*DTOR))**1.05
      Q9=0.5/CC*(PMASS/AREA)
      XTO=Q9*(ALOG(Q1/CA)+2.0*CB/Q0*(ATAN(CB/Q0)-ATAN((Q3+CB)/Q0)))
      XTO=XTO*Q5
C        WHEN  XTO < THICK ,THEN PENETRATION IS INCOMPLETE -- VR=0.0
      IF(XTO.LT.THICK)GOTO 185
C        COMPUTE A FIRST ESTIMATE FOR THE RESIDUAL VELOCITY
      RATIO=ABS((XTO-THICK)/THICK)
      IF(RATIO.GT.1.0)RATIO=ABS((XTO-THICK)/XTO)
      VR=RATIO*VS
      IFLGM=0
      IFLGP=0
      IREP=0
  160 IREP=IREP+1
      IF(IREP.GT.100)GOTO 910
      IF(IFLGP.EQ.1.AND.IFLGM.EQ.1)GOTO 180
C        COMPUTE THE PREDICTED TARGET PLATE THICKNESS
      Q2=CA+CB*VR+CC*VR**2
      Q4=2.0*CC*VR
      XT=Q9*(ALOG(Q1/Q2)+2.0*CB/Q0*(ATAN((Q4+CB)/Q0)-ATAN((Q3+CB)/Q0)))
C        ACCOUNT FOR OBLIQUE ANGLE IMPACT
      XT=XT*Q5
      IF(XT.GT.THICKP)GOTO 170
      IF(XT.LT.THICKM)GOTO 175
C        FALLING THROUGH THE ABOVE IF STATEMENTS MEANS THAT TOLERANCE
C        ON THE PLATE THICKNESS HAS BEEN MET WITH THE CURRENT VALUE
C        FOR THE RESIDUAL VELOCITY
      GOTO 185
  170 VR=VR+DELV
C        IFLGP=1 MEANS THAT THE VALUE FOR VR IS TOO LOW
      IFLGP=1
      GOTO 160
```

```
  175 VR=VR-DELV
C         IFLGM=1 MEANS THAT THE VALUE FOR VR IS TOO HIGH
      IFLGM=1
      GOTO 160
  180 DELV=DELV/2.0
C         THE VALUE FOR VR HAS OVERSHOT THE TOLERANCE LEVEL FOR
C         THICKNESS MEANING THAT THE VALUE FOR DELV IS TOO LARGE
      IFLGP=0
      IFLGM=0
      IF(DELV.LT.0.1)GOTO 910
      GOTO 160
185   VR=VR/100.0
C         COMPUTE DEVIANT  AND RELATIVE ERROR AND CORRESPONDING SUMMATION
      D=VR-VRE
      ICTD=ICTD+1
      SUMD=SUMD+D
      SUMDSQ=SUMDSQ+D**2
      RELERR=1000.0
      IF(VRE.LE.0.0)GOTO 186
      RELERR=D/VRE
      GOTO 187
  186 IF(VR.LE.0.0)RELERR=0.0
  187 IF(RELERR.GE.500.0)GOTO 189
      ICTE=ICTE+1
  189 CONTINUE
      SUMRE=SUMRE+RELERR
      SUMRES=SUMRES+RELERR**2
      WRITE(6,195)IDN,TRHO,TBHN,THICK,ANG,PMASS,PDIA,VSP,RMASS,HDIA,
     1   VRE,VR,D,SUMD,SUMDSQ,RELERR,SUMRE,SUMRES
  195 FORMAT(1H ,A6,F6.2,F6.1,F8.3,F5.1,F6.2,F6.3,F8.1,F7.2,
     1    F7.3,4F8.1,F10.1,3F8.3 )
      ICT=ICT+1
      GOTO 150
  200 CONTINUE
C         FIND THE MEAN,VARIANCE AND STANDARD DEVIATION OF
C         DEVIANTS AND RELATIVE ERROR
      CT=ICTD
      CT1=ICTD-1
      DBAR=SUMD/CT
      DVAR=(SUMDSQ-DBAR**2*CT)/CT1
      DSD=SQRT(DVAR)
      CT=ICTE
      CT1=ICTE-1
      EBAR=SUMRE/CT
      EVAR=(SUMRES-EBAR**2*CT)/CT1
      ESD-SQRT(EVAR)
      WRITE(6,220)ICTD
```

```
      WRITE(6,210)DBAR,DVAR,DSD
      WRITE(6,220)ICTE
      WRITE(6,215)EBAR,EVAR,ESD
  210 FORMAT(1HO,10X,37HMEAN, VARIANCE AND STANDARD DEVIATION ,2X,
     1    14HOF DEVIANTS  = , 3F10.1 )
  215 FORMAT(1HO,10X,37HMEAN, VARIANCE AND STANDARD DEVIATION ,2X,
     1    17HOF RELATIVE ERROR , 3F10.5)
C         PRINT NUMBER OF POINTS
      WRITE(6,220)ICT
  220 FORMAT(1HO,10X,18HNUMBER OF POINTS = , I5)
      IF(IDN.EQ. 6HEND    )GOTO 900
      GOTO 100
  900 WRITE(6,905)
  905 FORMAT(1HO,30X,10HEND OF RUN )
      STOP
  910 WRITE(6,915) IDN,IREP,DELV
  915 FORMAT(1HO,10X,A6,2X,19HDID NOT CONVERGE IN , I5,2X,
     1       10HITERATIONS,5X,6HDELV = , F10.5 )
      GOTO 150
      END
*     DATA
TITANIUM ALLOY
    1.0  4.48 190.0     .127   .0  1.95  .759  567.84  521.21   1.88
    2.0  4.48 190.0     .127   .0  1.95  .759 1461.82 1294.18    .91
    3.0  4.48 190.0     .318   .0  1.95  .759  880.26  590.40 -10.00
    4.0  4.48 190.0     .318   .0  1.95  .759 1355.45 1083.56   1.63
    5.0  4.48 190.0     .635   .0  1.95  .759 1491.08  683.36   1.73
    6.0  4.48 190.0     .635   .0  1.95  .759 1986.38 1127.15    .56
    7.0  4.48 190.0    1.270   .0  1.95  .759 2371.65  361.61 -10.00
    8.0  4.48 190.0     .127   .0  3.89 1.013  798.88  672.69   3.83
    9.0  4.48 190.0     .127   .0  3.89 1.013 1032.66  957.58   1.72
   10.0  4.48 190.0     .318   .0  3.89 1.013  620.27  500.79   3.83
   11.0  4.48 190.0     .318   .0  3.89 1.013  773.28  582.78   3.81
   12.0  4.48 190.0     .318   .0  3.89 1.013 1499.01 1251.81   2.43
   13.0  4.48 190.0     .635   .0  3.89 1.013 1505.71  774.50   3.24
   14.0  4.48 190.0     .635   .0  3.89 1.013 1526.13  979.32 -10.00
   15.0  4.48 190.0     .635   .0  3.89 1.013 2455.16 1367.33    .12
   16.0  4.48 190.0    1.270   .0  3.89 1.013 2551.79 1165.86    .57
   17.0  4.48 190.0     .127   .0  7.78 1.267  640.99  561.44   7.72
   18.0  4.48 190.0     .127   .0  7.78 1.267  959.21  874.78   7.72
   19.0  4.48 190.0     .318   .0  7.78 1.267  975.97  785.47   7.72
   20.0  4.48 190.0     .635   .0  7.78 1.267 1484.38  994.87 -10.00

RHA
    1.0  7.78 135.0     .046   .0  1.95  .759  888.49  848.87 -10.00
    2.0  7.78 135.0     .152   .0  1.95  .759 1211.58 1014.98 -10.00
    3.0  7.78 300.0     .318   .0  1.95  .759 1521.26 1196.34 -10.00
```

4.0	7.78	305.0	.635	.0	1.95	.759	1394.46	460.25	-10.00
5.0	7.78	393.0	.152	.0	1.95	.759	609.90	367.89	-10.00
6.0	7.78	135.0	.046	.0	3.89	1.013	302.06	277.37	-10.00
7.0	7.78	135.0	.152	.0	3.89	1.013	393.50	256.03	-10.00
8.0	7.78	135.0	.318	.0	3.89	1.013	883.62	542.54	-10.00
9.0	7.78	300.0	.318	.0	3.89	1.013	879.65	583.69	-10.00
10.0	7.78	300.0	.318	.0	3.89	1.013	1466.09	1164.34	-10.00
11.0	7.78	300.0	.635	.0	3.89	1.013	1466.09	687.32	-10.00
12.0	7.78	300.0	.318	.0	7.78	1.267	909.52	690.37	-10.00
13.0	7.78	300.0	.318	.0	15.56	1.491	916.53	754.38	-10.00
14.0	7.78	300.0	.318	.0	15.56	1.491	1425.55	1179.58	-10.00
15.0	7.78	300.0	.635	.0	15.56	1.491	1432.56	1037.84	-10.00
16.0	7.78	305.0	.635	.0	15.56	1.491	1556.00	1109.47	-10.00
17.0	7.78	332.0	1.270	.0	15.56	1.491	1660.55	759.56	-10.00

END

SAMPLE OUTPUT FOR Z/F EQUATION PREDICTING RESIDUAL VELOCITY

TITANIUM ALLOY

NR	TRHT	TEMP	THICK	ANG	MASS	PDIA	VS	PMASS	HDIA	VRE	VR	DEV	SUM	SQ	R.E.	SUM	SQ
1.0	4.44	190.0	.127	.0	1.95	.759	567.0	1.88	.000	521.2	433.0	-83.2	-83.2	6920.2	-.160	-.160	.025
2.0	4.44	190.0	.127	.0	1.95	.759	1461.6	.91	.000	1294.2	1323.1	28.9	-54.3	7755.9	.022	-.137	.026
3.0	4.44	190.0	.318	.0	1.95	.759	380.3	-10.00	.000	590.4	576.8	-13.6	-67.9	7942.2	-.023	-.160	.027
4.0	4.44	190.0	.318	.0	1.95	.759	1355.5	1.63	.000	1083.6	1027.8	-55.8	-123.6	11052.1	-.051	-.212	.029
5.0	4.44	190.0	.635	.0	1.95	.759	1491.1	1.73	.000	683.4	840.0	156.7	33.0	35601.8	.229	.018	.082
6.0	4.44	190.0	.635	.0	1.95	.759	1986.4	.56	.000	1127.1	1239.4	112.2	145.3	48197.8	.100	.117	.092
7.0	4.44	190.0	1.270	.0	1.95	.759	2371.7	-10.00	.000	381.6	878.3	496.6	641.9	294850.5	1.301	1.419	1.785
8.0	4.44	190.0	.127	.0	3.89	1.013	796.9	3.83	.000	672.7	691.9	19.2	661.1	295218.2	.029	1.447	1.786
9.0	4.44	190.0	.127	.0	3.89	1.013	1032.7	1.72	.000	957.7	922.5	-35.2	625.9	296454.7	-.037	1.410	1.788
10.0	4.44	190.0	.318	.0	3.89	1.013	620.3	3.83	.000	500.8	319.4	-181.4	444.5	329353.1	-.362	1.048	1.919
11.0	4.44	190.0	.318	.0	3.89	1.013	773.3	3.81	.000	582.8	499.0	-83.8	360.7	336378.4	-.144	.904	1.939
12.0	4.44	190.0	.318	.0	3.89	1.013	1499.0	2.43	.000	1251.8	1193.5	-58.4	302.4	339703.4	-.047	.858	1.942
13.0	4.44	190.0	.635	.0	3.89	1.013	1505.7	3.24	.000	774.5	917.6	143.1	445.4	360247.6	.185	1.042	1.976
14.0	4.44	190.0	.635	.0	3.49	1.013	1526.1	-10.00	.000	979.3	934.9	-44.4	401.0	362217.5	-.045	.997	1.978
15.0	4.44	190.0	.635	.0	3.89	1.013	2455.2	.12	.000	1367.3	1678.7	311.4	712.4	459181.4	.228	1.225	2.030
16.0	4.4	190.0	1.270	.0	3.89	1.013	2551.6	.57	.000	1165.9	1123.7	-42.2	670.3	460960.3	-.036	1.189	2.031
17.0	4.44	190.0	.127	.0	7.78	1.267	641.0	7.72	.000	561.4	554.5	-6.9	663.4	461007.9	-.012	1.176	2.031
18.0	4.44	190.0	.127	.0	7.78	1.267	959.2	7.72	.000	874.8	873.8	-1.0	662.3	461009.0	-.001	1.175	2.031
19.0	4.44	190.0	.318	.0	7.78	1.267	976.0	7.72	.000	785.5	763.9	-21.5	640.8	461473.3	-.027	1.148	2.032
20.0	4.44	190.0	.635	.0	7.78	1.267	1484.4	-10.00	.000	994.9	1019.8	24.9	665.7	462092.6	.025	1.173	2.032

NUMBER OF POINTS = 20

MEAN, VARIANCE AND STANDARD DEVIATION OF DEVIANTS = 33.3 23154.6 152.2

NUMBER OF POINTS = 20

MEAN, VARIANCE AND STANDARD DEVIATION OF RELATIVE ERROR .05864 .10335 .32148

NUMBER OF POINTS = 20

SAMPLE DATA [illegible] Z/F EQUATION PREDICTING RESIDUAL VELOCITY

RHA

R	TRE	TRIM	THICK	[illegible]	MASS	PDIA	VS	RMASS	HDIA	VRE	VR	DEV	SUM	SQ	R.E.	SUM	SQ
1.0	7.7	135.0	.046	.0	1.95	.759	385.5	-10.00	.000	348.9	332.5	-16.3	-16.3	267.0	-.019	-.019	.000
2.0	7.7	135.0	.152	.0	1.95	.759	1211.6	-10.00	.000	1015.0	1005.5	-9.5	-25.8	357.2	-.009	-.029	.000
3.0	7.7	300.0	.318	.0	1.95	.759	1521.3	-10.00	.000	1196.3	960.9	-235.4	-261.3	55780.0	-.197	-.225	.039
4.0	7.7	305.0	.635	.0	1.95	.759	1394.5	-10.00	.000	460.3	319.8	-140.5	-401.7	75509.2	-.305	-.531	.132
5.0	7.7	393.0	.152	.0	1.95	.759	609.0	-10.00	.000	367.9	284.6	-83.2	-485.0	82438.4	-.226	-.757	.184
6.0	7.7	135.0	.046	.0	3.89	1.013	302.1	-10.00	.000	277.4	252.4	-25.0	-509.9	83061.2	-.090	-.847	.192
7.0	7.7	135.0	.152	.0	3.89	1.013	393.5	-10.00	.000	256.0	236.8	-19.2	-529.1	83429.9	-.075	-.922	.197
8.0	7.7	135.0	.318	.0	3.89	1.013	383.6	-10.00	.000	542.5	564.1	21.6	-507.6	83894.4	.040	-.882	.199
9.0	7.7	300.0	.318	.0	3.89	1.013	379.6	-10.00	.000	583.7	424.4	-159.3	-666.8	109259.5	-.273	-1.155	.273
10.0	7.7	300.0	.318	.0	3.89	1.013	1466.1	-10.00	.000	1164.3	970.9	-193.4	-860.3	146676.8	-.166	-1.321	.301
11.0	7.7	300.0	.635	.0	3.89	1.013	1466.1	-10.00	.000	687.3	519.7	-167.6	-1027.9	174783.1	-.244	-1.565	.360
12.0	7.7	300.0	.318	.0	7.78	1.267	909.5	-10.00	.000	690.4	557.3	-133.0	-1161.0	192482.1	-.193	-1.758	.397
13.0	7.7	300.0	.318	.0	15.55	1.491	916.5	-10.00	.000	754.4	674.4	-80.0	-1241.0	198881.4	-.106	-1.864	.409
14.0	7.7	300.0	.318	.0	15.56	1.491	1425.6	-10.00	.000	1179.6	1150.6	-28.9	-1269.9	199719.0	-.025	-1.888	.409
15.0	7.7	300.0	.635	.0	15.56	1.491	1432.6	-10.00	.000	1037.8	904.0	-133.8	-1403.7	217626.3	-.129	-2.017	.426
16.0	7.7	305.0	.635	.0	15.56	1.491	1556.0	-10.00	.000	1109.5	1005.2	-104.3	-1508.0	228499.5	-.094	-2.111	.435
17.0	7.7	332.0	1.270	.0	15.56	1.491	1660.5	-10.00	.000	759.6	566.0	-193.5	-1701.5	265952.4	-.255	-2.366	.500

NUMBER OF POINTS = 17

MEAN, VARIANCE AND STANDARD DEVIATION OF DEVIANTS = -100.1 5978.1 77.3

NUMBER OF POINTS = 17

MEAN, VARIANCE AND STANDARD DEVIATION OF RELATIVE ERROR -.13918 .01065 .10321

NUMBER OF POINTS = 17

END OF RUN

```
C
C
C
COMM      PROGRAM USING THE THOR EQUATION TO PREDICT RESIDUAL VELOCITY
C
C         GLOSSARY OF VARIABLES
C
C
C   ***           IDENTIFIES REQUIRED INPUT DATA
C     *           IDENTIFIES INPUT DATA WHICH IS NOT REQUIRED
C
C
C   ***   ANG    - THE ANGLE OF THE TARGET PLATE WITH RESPECT TO
C                   LINE OF FLIGHT  - OBLIQUITY  (DEGREES)
C         AREA   - THE PROJECTED CROSS-SECTIONAL AREA OF PROJECTILE
C                   ON IMPACT
C         D      - THE DEVIANT  = COMPUTED VALUE MINUS EXPERIMENTAL VALUE
C         DBAR   - THE AVERAGE (MEAN) VALUE OF THE DEVIANTS
C         DSD    - THE STANDARD DEVIATION OF THE DEVIANTS
C         DTOR   - CONVERSION FACTOR -  DEGREES TO RADIANS
C         DVAR   - THE VARIANCE OF THE DEVIANTS
C         E1     - CONSTANT BASED ON LEAST SQUARE FIT TO DATA
C         E2     - CONSTANT BASED ON LEAST SQUARE FIT TO DATA
C         E3     - CONSTANT BASED ON LEAST SQUARE FIT TO DATA
C         E4     - CONSTANT BASED ON LEAST SQUARE FIT TO DATA
C         E5     - CONSTANT BASED ON LEAST SQUARE FIT TO DATA
C         EBAR   - THE AVERAGE (MEAN) VALUE OF THE RELATIVE ERROR
C         ESD    - THE STANDARD DEVIATION OF THE RELATIVE ERROR
C         EVAR   - THE VARIANCE OF THE RELATIVE ERROR
C     *   HDIA   - THE DIAMETER OF THE HOLE MADE IN THE TARGET  (CM)
C         ICT    - INDEX TO COUNT NUMBER OF DATA CARDS FOR ONE TARGET
C         ICTD   - INDEX COUNTER ON NUMBER OF POINTS FOR DEVIANTS
C         ICTE   - INDEX COUNTER ON NUMBER OF POINTS FOR RELATIVE ERROR
C     *   IDN    - AN IDENTIFICATION NUMBER OR SYMBOL-DESIGNATES SHOT NR.
C   ***   PDIA   - DIAMETER OF THE PROJECTILE (CM)
C   ***   PMASS  - MASS OF PROJECTILE  (GRAMS)
C         RELERR - THE RELATIVE ERROR OF COMPUTED VS. EXPERIMENTAL
C     *   RMASS  - THE RECOVERED PROJECTILE MASS  (GRAMS)
C         SUMD   - THE SUM OF THE DEVIANTS
C         SUMDSQ - THE SUM OF THE DEVIANT SQUARED
C         SUMRE  - THE SUM OF THE RELATIVE ERROR
C         SUMRES - THE SUM OF THE RELATIVE ERROR SQUARED
C     *   TBHN   - THE TARGET BRINELL HARDNESS NUMBER  (KG/SQ MM)
C   ***   THICK  - THE THICKNESS OF THE TARGET PLATE  (CM)
C     *   TRHO   - THE DENSITY OF THE TARGET PLATE  (G/CC)
C         VR     - PREDICTED RESIDUAL VELOCITY  (M/S)
C     *   VRE    - THE EXPERIMENTAL RESIDUAL VELOCITY  (M/S)
```

```
C   ***   VSP    - THE EXPERIMENTAL STRIKING VELOCITY  (M/S)
C
      DATA PI,DTOR / 3.141592654, 0.0174532925 /
   10 FORMAT( A6,2F6.1,F8.3,F5.1,2F6.3,2F8.1,2F7.2)
   11 FORMAT(5F10.3)
   12 FORMAT(10A6)
   20 FORMAT(1H0,10X,13HEXPONENTS ARE , 5F10.3  / )
  100 CONTINUE
      WRITE(6,103)
  103 FORMAT(1H1)
      WRITE(6,106)
  106 FORMAT(1H0,20X,42HSAMPLE OUTPUT FOR THOR EQUATION PREDICTING ,
     1    18H RESIDUAL VELOCITY  / )
C          READ CARD WHICH IDENTIFIES TARGET MATERIAL
      READ(5,12)TGT1,TGT2,TGT3
      WRITE(6,12)TGT1,TGT2,TGT3
      READ(5,11)E1,E2,E3,E4,E5
      WRITE(6,20)E1,E2,E3,E4,E5
      WRITE(6,110)
  110 FORMAT(1H0,4X,39HNR   TRHO  TBHN   THICK  ANG  MASS  PDIA ,6X,
     1    2HVS,2X,12HRMASS    HDIA ,5X,3HVRE,6X,2HVR,5X,3HDEV,5X,
     2     3HSUM,8X,2HSQ,4X,4HR.E.,5X,3HSUM,6X,2HSQ )
      ICTR=0
      ICTL=0
      SUMD=0.0
      SUMDSQ=0.0
      SUMRE=0.0
      SUMRES=0.0
      ICT=0
C         ONE BLANK CARD USED TO SEPARATE DATA FOR DIFFERENT TARGETS
C         A CARD WITH  END  PUNCHED IN THE FIRST THREE COLUMNS
C         WILL TERMINATE THE PROGRAM
  150 READ(5,10)IDN,TRHO,TBHN,THICK,ANG,PMASS,PDIA,VSP,VRE,RMASS,HDIA
      IF(TRHO.LE.0.0)GOTO 200
C         COMPUTE PROJECTILE CROSS-SECTIONAL AREA
      AREA=PI*(PDIA/2.0)**2
C         THE UNIT OF VELOCITY TO BE USED IS CM/SEC
      VS=VSP*100.0
      Q1=10.0**E1
      Q2=(THICK*AREA)**E2
      Q3=PMASS**E3
      Q4=(1.0/COS(ANG*DTOR))**E4
      Q5=VS**E5
C         COMPUTE THE PREDICTED RESIDUAL VELOCITY
      VR=(VS-Q1*Q2*Q3*Q4*Q5)/100.0
C         COMPUTE DEVIANT  AND RELATIVE ERROR AND CORRESPONDING SUMMATION
      D=VR-VRE
```

```
      SUMD=SUMD+D
      SUMDSQ=SUMDSQ+D**2
      ICTD=ICTD+1
      RELERR=1000.0
      IF(VRE.LE.0.0)GOTO 186
      RELERR=D/VRE
      GOTO 187
  186 IF(VR.LE.0.0)RELERR=0.0
  187 IF(RELERR.GE.500.0)GOTO 189
      ICTE=ICTE+1
  189 CONTINUE
      SUMRE=SUMRE+RELERR
      SUMRES=SUMRES+RELERR**2
      WRITE(6,195)IDN,TRHO,TBHN,THICK,ANG,PMASS,PDIA,VSP,RMASS,HDIA,
     1   VRE,VR,D,SUMD,SUMDSQ,RELERR,SUMRE,SUMRES
  195 FORMAT(1H ,A6,F6.2,F6.1,F8.3,F5.1,F6.2,F6.3,F8.1,F7.2,
     1     F7.3,4F8.1,F10.1,3F8.3 )
      ICT=ICT+1
      GOTO 150
  200 CONTINUE
C         FIND THE MEAN,VARIANCE AND STANDARD DEVIATION OF
C         DEVIANTS   AND RELATIVE ERROR
      CT=ICTD
      CT1=ICTD-1
      DBAR=SUMD/CT
      DVAR=(SUMDSQ-DBAR**2*CT)/CT1
      DSD=SQRT(DVAR)
      CT=ICTE
      CT1=ICTE-1
      EBAR=SUMRE/CT
      EVAR=(SUMRES-EBAR**2*CT)/CT1
      ESD=SQRT(EVAR)
      WRITE(6,220)ICTD
      WRITE(6,210)DBAR,DVAR,DSD
      WRITE(6,220)ICTE
      WRITE(6,215)EBAR,EVAR,ESD
  210 FORMAT(1H0,10X,37HMEAN, VARIANCE AND STANDARD DEVIATION ,2X,
     1    14HOF DEVIANTS =  , 3F10.1 )
  215 FORMAT(1H0,10X,37HMEAN, VARIANCE AND STANDARD DEVIATION ,2X,
     1    17HOF RELATIVE ERROR , 3F10.5)
C         PRINT NUMBER OF POINTS
      WRITE(6,220)ICT
  220 FORMAT(1H0,10X,18HNUMBER OF POINTS = , I5)
      IF(IDN.EQ. 6HEND    )GOTO 900
      GOTO 100
  900 WRITE(6,905)
  905 FORMAT(1H0,30X,10HEND OF RUN )
```

```
      STOP                                                                        142
      END                                                                         143
*     DATA                                                                        144
TITANIUM ALLOY
    4.888       1.103       -1.095       1.369       0.167
   1.0   4.48 190.0      .127     .0   1.95   .759  567.84  521.21    1.88
   2.0   4.48 190.0      .127     .0   1.95   .759 1461.82 1294.18     .91
   3.0   4.48 190.0      .318     .0   1.95   .759  880.26  590.40  -10.00
   4.0   4.48 190.0      .318     .0   1.95   .759 1355.45 1083.56    1.63
   5.0   4.48 190.0      .635     .0   1.95   .759 1491.08  683.36    1.73
   6.0   4.48 190.0      .[illegible]5     .0   1.95   .759 1986.38 1127.15     .56
   7.0   4.48 190.0     1.270     .0   1.95   .759 2371.65  381.61  -10.00
   8.0   4.48 190.0      .127     .0   3.89  1.013  798.88  672.69    3.83
   9.0   4.48 190.0      .127     .0   3.89  1.013 1032.66  957.68    1.72
  10.0   4.48 190.0      .318     .0   3.89  1.013  620.27  500.79    3.83
  11.0   4.48 190.0      .318     .0   3.89  1.013  773.28  582.78    3.81
  12.0   4.48 190.0      .318     .0   3.89  1.013 1499.01 1251.81    2.43
  13.0   4.48 190.0      .635     .0   3.89  1.013 1505.71  774.50    3.24
  14.0   4.48 190.0      .635     .0   3.89  1.013 1526.13  979.32  -10.00
  15.0   4.48 190.0      .635     .0   3.89  1.013 2455.16 1367.33     .12
  16.0   4.48 190.0     1.270     .0   3.89  1.013 2551.79 1165.86     .57
  17.0   4.48 190.0      .127     .0   7.78  1.267  640.99  561.44    7.72
  18.0   4.48 190.0      .127     .0   7.78  1.267  959.21  874.78    7.72
  19.0   4.48 190.0      .318     .0   7.78  1.267  975.97  785.47    7.72
  20.0   4.48 190.0      .635     .0   7.78  1.267 1484.38  994.87  -10.00

RHA
    5.690       0.889       -0.945       0.989       0.019
   1.0   7.78 135.0      .046     .0   1.95   .759  888.49  848.87  -10.00
   2.0   7.78 135.0      .152     .0   1.95   .759 1211.58 1014.98  -10.00
   3.0   7.78 300.0      .318     .0   1.95   .759 1521.26 1196.34  -10.00
   4.0   7.78 305.0      .635     .0   1.95   .759 1394.46  460.25  -10.00
   5.0   7.78 393.0      .152     .0   1.95   .759  609.90  367.89  -10.00
   6.0   7.78 135.0      .046     .0   3.89  1.013  302.06  277.37  -10.00
   7.0   7.78 135.0      .152     .0   3.89  1.013  393.50  256.03  -10.00
   8.0   7.78 135.0      .318     .0   3.89  1.013  883.62  342.54  -10.00
   9.0   7.78 300.0      .318     .0   3.89  1.013  879.65  583.69  -10.00
  10.0   7.78 300.0      .318     .0   3.89  1.013 1466.09 1164.34  -10.00
  11.0   7.78 300.0      .635     .0   3.89  1.013 1466.09  687.32  -10.00
  12.0   7.78 300.0      .318     .0   7.78  1.267  909.52  690.37  -10.00
  13.0   7.78 300.0      .318     .0  15.56  1.491  916.53  754.38  -10.00
  14.0   7.78 300.0      .318     .0  15.56  1.491 1425.55 1179.58  -10.00
  15.0   7.78 300.0      .635     .0  15.56  1.491 1432.56 1037.84  -10.00
  16.0   7.78 305.0      .635     .0  15.56  1.491 1556.00 1109.47  -10.00
  17.0   7.78 332.0     1.270     .0  15.56  1.491 1660.55  759.56  -10.00
END
```

SAMPLE DATA [illegible] THEIR EQUATION PREDICTING RESIDUAL VELOCITY

TITA[illegible] ALLOY

COEFFICIENTS ARE [illegible] 1.193 -1.[illegible]95 1.369 .167

R	TRN	T[illegible]	THICK	NG	MASS	PDIA	VS	RMASS	HDIA	VRE	VR	DEV	SUM	SQ	R.E.	SUM	SQ
1.0	4.4-	19[illegible]	.127	.0	1.95	.759	567.[illegible]	1.88	.000	521.2	469.8	-52.4	-52.4	2750.4	-.101	-.101	.010
2.0	4.4	19[illegible]	.127	.0	1.95	.759	1461.5	.91	.000	1294.2	1345.8	51.6	-.8	5414.8	.040	-.061	.012
3.0	4.4	190.0	.318	.0	1.95	.759	980.3	-10.00	.000	590.4	585.9	-3.5	-4.4	5427.2	-.006	-.067	.012
4.0	4.4-	190.0	.318	.0	1.95	.759	1355.5	1.63	.000	1083.6	1040.1	-43.4	-47.8	7312.9	-.040	-.107	.013
5.0	4.4	190.0	.635	.0	1.95	.759	1491.1	1.73	.000	683.4	304.1	120.7	73.0	21891.2	.177	.070	.045
6.0	4.4-	190.0	.635	.0	1.95	.759	1386.4	.56	.000	1127.1	1265.7	138.5	211.5	41086.0	.123	.193	.060
7.0	4.4-	190.0	1.270	.0	1.95	.759	2371.7	-10.00	.000	381.6	777.1	395.5	607.0	197497.1	1.036	1.229	1.134
8.0	4.4-	190.0	.127	.0	3.89	1.013	798.[illegible]	3.83	.000	672.7	705.8	33.1	640.1	198593.1	.049	1.278	1.136
9.0	4.4-	190.0	.127	.0	3.49	1.013	1032.7	1.72	.000	957.7	935.5	-22.2	617.9	199085.1	-.023	1.255	1.137
10.0	4.4-	190.0	.318	.0	3.89	1.013	520.3	3.83	.000	500.8	374.7	-126.1	491.8	214987.6	-.252	1.003	1.200
11.0	4.4-	190.0	.318	.0	3.39	1.013	773.3	3.61	.000	582.8	518.5	-64.3	427.5	219121.6	-.110	.893	1.212
12.0	4.4-	190.0	.318	.0	3.49	1.013	1499.[illegible]	2.43	.000	1251.8	1214.4	-37.4	390.1	220518.7	-.030	.863	1.213
13.0	4.4-	190.0	.635	.0	3.89	1.013	1505.7	3.24	.000	774.5	895.0	120.5	510.7	235048.8	.156	1.019	1.237
14.0	4.4-	190.0	.635	.0	3.59	1.013	1526.1	-10.00	.000	979.3	914.1	-65.2	445.5	239304.3	-.067	.952	1.242
15.0	4.4-	190.0	.635	.0	3.89	1.013	2455.2	.12	.000	1367.3	1792.5	425.2	870.7	420105.3	.311	1.263	1.339
16.0	4.4-	190.0	1.270	.0	3.39	1.013	2551.[illegible]	.57	.000	1165.9	1119.3	-46.6	824.1	422276.4	-.040	1.223	1.340
17.0	4.4-	190.0	.127	.0	7.7[illegible]	1.267	541.[illegible]	7.72	.000	561.4	572.2	10.7	834.8	422391.9	.019	1.242	1.341
18.0	4.4-	190.0	.127	.0	7.7[illegible]	1.267	959.2	7.72	.000	874.8	885.6	10.8	845.6	422509.2	.012	1.255	1.341
19.0	4.4-	190.0	.318	.0	7.7[illegible]	1.267	976.[illegible]	7.72	.000	785.5	772.8	-12.6	833.0	422669.0	-.016	1.239	1.341
20.0	4.4-	190.0	.635	.0	7.7[illegible]	1.267	1484.4	-10.00	.000	994.9	1017.2	22.3	855.3	423167.2	.022	1.261	1.341

NUMBER OF POINTS = 2[illegible]

MEAN, VARIANCE AND STANDARD DEVIATION OF DEVIANTS = 42.8 20346.8 142.6

NUMBER OF POINTS = 2[illegible]

MEAN, VARIANCE AND STANDARD DEVIATION OF RELATIVE ERROR .06306 .06642 .25771

NUMBER OF POINTS = 2[illegible]

SAMPLE DATA FOR THOR EQUATION PREDICTING RESIDUAL VELOCITY

RHA

EXPONENTS ARE 5.500 .189 -.545 .989 .019

NR	TRHT	TBHN	THICK	ANG	MASS	PDIA	VS	RMASS	HDIA	VRE	VR	DEV	SUM	SQ	R.E.	SUM	SQ
1.0	7.78	135.0	.046	.0	1.95	.759	985.5	-10.00	.000	848.9	785.0	-63.9	-63.9	4080.6	-.075	-.075	.006
2.0	7.78	135.0	.152	.0	1.95	.759	1211.6	-10.00	.000	1015.0	910.3	-104.7	-168.6	15037.7	-.103	-.178	.016
3.0	7.78	300.0	.318	.0	1.95	.759	1521.3	-10.00	.000	1196.3	938.0	-258.3	-426.9	81763.0	-.216	-.396	.063
4.0	7.78	305.0	.635	.0	1.95	.759	1394.5	-10.00	.000	460.3	317.7	-142.6	-569.4	102092.5	-.310	-.706	.159
5.0	7.78	393.0	.152	.0	1.95	.759	609.9	-10.00	.000	367.9	312.5	-55.4	-624.8	105157.5	-.150	-.855	.182
6.0	7.78	135.0	.046	.0	3.89	1.013	302.1	-10.00	.000	277.4	213.8	-63.5	-688.3	109192.3	-.229	-1.084	.236
7.0	7.78	135.0	.152	.0	3.89	1.013	393.5	-10.00	.000	256.0	137.0	-119.1	-807.4	123372.0	-.465	-1.549	.450
8.0	7.78	135.0	.318	.0	3.89	1.013	983.6	-10.00	.000	542.5	381.5	-161.1	-968.5	149319.0	-.297	-1.846	.538
9.0	7.78	300.0	.318	.0	3.89	1.013	979.6	-10.00	.000	583.7	377.5	-206.2	-1174.6	191820.1	-.353	-2.199	.663
10.0	7.78	300.0	.318	.0	3.89	1.013	1466.1	-10.00	.000	1164.3	959.1	-205.3	-1379.9	233953.8	-.176	-2.375	.694
11.0	7.78	300.0	.635	.0	3.89	1.013	1466.1	-10.00	.000	687.3	528.5	-158.9	-1538.8	259188.7	-.231	-2.606	.748
12.0	7.78	300.0	.318	.0	7.78	1.267	909.5	-10.00	.000	690.4	521.0	-169.3	-1708.1	287862.1	-.245	-2.851	.808
13.0	7.78	300.0	.318	.0	15.56	1.491	916.5	-10.00	.000	754.4	647.0	-107.4	-1815.5	299400.0	-.142	-2.994	.828
14.0	7.78	300.0	.318	.0	15.56	1.491	1425.6	-10.00	.000	1179.6	1153.7	-25.9	-1841.4	300069.8	-.022	-3.016	.829
15.0	7.78	300.0	.635	.0	15.56	1.491	1432.6	-10.00	.000	1037.8	929.8	-108.0	-1949.4	311742.5	-.104	-3.120	.839
16.0	7.78	305.0	.635	.0	15.56	1.491	1556.0	-10.00	.000	1109.5	1052.4	-57.0	-2006.4	314993.9	-.051	-3.171	.842
17.0	7.78	332.0	1.270	.0	15.56	1.491	1660.5	-10.00	.000	759.6	726.9	-32.7	-2039.1	316062.1	-.043	-3.214	.844

NUMBER OF POINTS = 17

MEAN, VARIANCE AND STANDARD DEVIATION OF DEVIANTS = -119.9 4466.9 66.8

NUMBER OF POINTS = 17

MEAN, VARIANCE AND STANDARD DEVIATION OF RELATIVE ERROR -.18908 .01476 .12150

NUMBER OF POINTS = 17

END OF RUN

```
C
C
C
COMM     PROGRAM USING THE Z/F EQUATION TO PREDICT PLATE THICKNESS
C
C
C        GLOSSARY OF VARIABLES
C
C
C   ***            IDENTIFIES REQUIRED INPUT DATA
C     *            IDENTIFIES INPUT DATA WHICH IS NOT REQUIRED
C
C
C   ***     ANG    - THE ANGLE OF THE TARGET PLATE WITH RESPECT TO
C                      LINE OF FLIGHT  - OBLIQUITY  (DEGREES)
C           AREA   - THE PROJECTED CROSS-SECTIONAL AREA OF PROJECTILE
C                      ON IMPACT
C           C1     - CONSTANT BASED ON LEAST SQUARE FIT TO THOR DATA
C           C2     - CONSTANT BASED ON LEAST SQUARE FIT TO THOR DATA
C           C3     - CONSTANT BASED ON LEAST SQUARE FIT TO THOR DATA
C           D      - THE DEVIANT  = COMPUTED VALUE MINUS EXPERIMENTAL VALUE
C           DBAR   - THE AVERAGE (MEAN) VALUE OF THE DEVIANTS
C           DSD    - THE STANDARD DEVIATION OF THE DEVIANTS
C           DTOR   - CONVERSION FACTOR -  DEGREES TO RADIANS
C           DVAR   - THE VARIANCE OF THE DEVIANTS
C           EBAR   - THE AVERAGE (MEAN) VALUE OF THE RELATIVE ERROR
C           ESD    - THE STANDARD DEVIATION OF THE RELATIVE ERROR
C           EVAR   - THE VARIANCE OF THE RELATIVE ERROR
C     *     HDIA   - THE DIAMETER OF THE HOLE MADE IN THE TARGET  (CM)
C           ICT    - INDEX TO COUNT NUMBER OF DATA CARDS FOR ONE TARGET
C     *     IDN    - AN IDENTIFICATION NUMBER OR SYMBOL-DESIGNATES SHOT NR.
C   ***     PDIA   - DIAMETER OF THE PROJECTILE (CM)
C   ***     PMASS  - MASS OF PROJECTILE  (GRAMS)
C           RELERR - THE RELATIVE ERROR OF COMPUTED VS. EXPERIMENTAL
C     *     RMASS  - THE RECOVERED PROJECTILE MASS   (GRAMS)
C           SUMD   - THE SUM OF THE DEVIANTS
C           SUMDSQ - THE SUM OF THE DEVIANT SQUARED
C           SUMRE  - THE SUM OF THE RELATIVE ERROR
C           SUMRES - THE SUM OF THE RELATIVE ERROR SQUARED
C   ***     TBHN   - THE TARGET BRINELL HARDNESS NUMBER  (KG/SQ MM)
C     *     THICK  - THE THICKNESS OF THE TARGET PLATE  (CM)
C   ***     TRHO   - THE DENSITY OF THE TARGET PLATE  (G/CC)
C   ***     VRE    - THE EXPERIMENTAL RESIDUAL VELOCITY  (M/S)
C   ***     VSE    - THE EXPERIMENTAL STRIKING VELOCITY  (M/S)
C           XT     - THE PREDICTED TARGET PLATE THICKNESS  (CM)
C
      DATA PI,DTOR / 3.141592654, 0.0174532925 /
```

```
   10 FORMAT( A6,2F6.1,F8.3,F5.1,2F6.3,2F8.1,2F7.2)
   12 FORMAT(10A6)
      C1=0.70
      C2=0.23
      C3=0.50
  100 CONTINUE
      WRITE(6,103)
  103 FORMAT(1H1)
      WRITE(6,106)
  106 FORMAT(1H0,20X,42HSAMPLE OUTPUT FOR  Z/F EQUATION PREDICTING ,
     1   16H PLATE THICKNESS  / )
C         READ CARD WHICH IDENTIFIES TARGET MATERIAL
      READ(5,12)TGT1,TGT2,TGT3
      WRITE(6,12)TGT1,TGT2,TGT3
      WRITE(6,110)
  110 FORMAT(1H0,4X,31HNR  TRHO  TBHN  ANG  MASS  PDIA , 6X,2HVS,6X,
     1     24HVR  RMASS  HDIA  THICK , 6X,2HXT,5X,3HDEV,5X,
     2     3HSUM,6X,2HSQ,4X,4HR.E.,5X,3HSUM,6X,2HSQ )
      SUMD=0.0
      SUMDSQ=0.0
      SUMRE=0.0
      SUMRES=0.0
      ICT=0
C        ONE BLANK CARD USED TO SEPARATE DATA FOR DIFFERENT TARGETS
C        A CARD WITH  END  PUNCHED IN THE FIRST THREE COLUMNS
C        WILL TERMINATE THE PROGRAM
  150 READ(5,10)IDN,TRHO,TBHN,THICK,ANG,PMASS,PDIA,VSP,VRE,RMASS,HDIA
      IF(TRHO.LE.0.0)GOTO 200
C        COMPUTE PROJECTILE CROSS-SECTIONAL AREA
      AREA=PI*(PDIA/2.0)**2
C        THE UNIT OF VELOCITY TO BE USED IS CM/SEC
      VS=VSP*100.0
      VR=VRE*100.0
C        COMPUTE COEFFICIENTS AND OTHER QUANTITIES
C           (NOTE :  9.8E7  CONVERTS THE BRINELL HARDNESS NUMBER
C                     FROM  KG/MM**2  TO  DYNE/CM**2 )
      CA=9.8E7*TBHN*C1
      CB=SQRT(9.857*TBHN*TRHO)*C2
      CC=TRHO*C3
      QX=4.0*C1*C3-C2**2
      Q=QX*9.8E7*TBHN*TRHO
      Q0=SQRT(Q)
      Q1=CA+CB*VS+CC*VS**2
      Q2=CA+CB*VR+CC*VR**2
      Q3=2.0*CC*VS
      Q4=2.0*CC*VR
      Q5=(COS(ANG*DTOR))**1.05
```

```
      Q9=0.5/CC*(PMASS/AREA)
C        COMPUTE THE PREDICTED TARGET PLATE THICKNESS
      XT=Q9*(ALOG(Q1/Q2)+2.0*CB/Q0*(ATAN((Q4+CB)/Q0)-ATAN((Q3+CB)/Q0)))
C        ACCOUNT FOR OBLIQUE ANGLE IMPACT
      XT=XT*Q5
C        COMPUTE DEVIANT  AND RELATIVE ERROR AND CORRESPONDING SUMMATION
      D=XT-THICK
      SUMD=SUMD+D
      SUMDSQ=SUMDSQ+D**2
      RELERR=D/THICK
      SUMRE=SUMRE+RELERR
      SUMRES=SUMRES+RELERR**2
      WRITE(6,155)IDN,TRHO,TBHN,ANG,PMASS,PDIA,VSP,VRE,RMASS,HDIA,
     1   THICK,XT,D,SUMD,SUMDSQ,RELERR,SUMRE,SUMRES
      ICT=ICT+1
      GOTO 150
  155 FORMAT(1H ,A6,F6.2,F6.1,F5.1,F6.2,F6.3,2F8.1,2F7.2,8F8.3)
  200 CT=ICT
      CT1=ICT-1
C        FIND THE MEAN,VARIANCE AND STANDARD DEVIATION OF
C        DEVIANTS AND RELATIVE ERROR
      DBAR=SUMD/CT
      DVAR=(SUMDSQ-DBAR**2*CT)/CT1
      DSD=SQRT(DVAR)
      EBAR=SUMRE/CT
      EVAR=(SUMRES-EBAR**2*CT)/CT1
      ESD=SQRT(EVAR)
      WRITE(6,210)DBAR,DVAR,DSD
      WRITE(6,215)EBAR,EVAR,ESD
  210 FORMAT(1H0,10X,37HMEAN, VARIANCE AND STANDARD DEVIATION ,2X,
     1   14HOF DEVIANTS =   , 3F10.5 )
  215 FORMAT(1H0,10X,37HMEAN, VARIANCE AND STANDARD DEVIATION ,2X,
     1   17HOF RELATIVE ERROR , 3F10.5)
C        PRINT NUMBER OF POINTS
      WRITE(6,220)ICT
  220 FORMAT(1H0,10X,18HNUMBER OF POINTS = , I5)
      IF(IDN.EQ. 6HEND    )GOTO 900
      GOTO 100
  900 WRITE(6,905)
  905 FORMAT(1H0,30X,10HEND OF RUN )
      STOP
      END
*     DATA
TITANIUM ALLOY
   1.0   4.48 190.0     .127    .0  1.95   .759   567.84   521.21    1.88
   2.0   4.48 190.0     .127    .0  1.95   .759  1461.82  1294.18     .91
   3.0   4.48 190.0     .318    .0  1.95   .759   880.26   590.40  -10.00
```

4.0	4.48	190.0	.318	.0	1.95	.759	1355.45	1083.56	1.63
5.0	4.48	190.0	.635	.0	1.95	.759	1491.08	683.36	1.73
6.0	4.48	190.0	.635	.0	1.95	.759	1986.38	1127.15	.56
7.0	4.48	190.0	1.270	.0	1.95	.759	2371.65	381.61	-10.00
8.0	4.48	190.0	.127	.0	3.89	1.013	798.88	672.69	3.83
9.0	4.48	190.0	.127	.0	3.89	1.013	1032.66	957.68	1.72
10.0	4.48	190.0	.318	.0	3.89	1.013	620.27	500.79	3.83
11.0	4.48	190.0	.318	.0	3.89	1.013	773.28	582.78	3.81
12.0	4.48	190.0	.318	.0	3.89	1.013	1499.01	1251.81	2.43
13.0	4.48	190.0	.635	.0	3.89	1.013	1505.71	774.50	3.24
14.0	4.48	190.0	.635	.0	3.89	1.013	1526.13	979.32	-10.00
15.0	4.48	190.0	.635	.0	3.89	1.013	2455.16	1367.33	.12
16.0	4.48	190.0	1.270	.0	3.89	1.013	2551.79	1165.86	.57
17.0	4.48	190.0	.127	.0	7.78	1.267	640.99	561.44	7.72
18.0	4.48	190.0	.127	.0	7.78	1.267	959.21	874.78	7.72
19.0	4.48	190.0	.318	.0	7.78	1.267	975.97	785.47	7.72
20.0	4.48	190.0	.635	.0	7.78	1.267	1484.38	994.87	-10.00
RHA									
1.0	7.78	135.0	.046	.0	1.95	.759	888.49	848.87	-10.00
2.0	7.78	135.0	.152	.0	1.95	.759	1211.58	1014.98	-10.00
3.0	7.78	300.0	.318	.0	1.95	.759	1521.26	1196.34	-10.00
4.0	7.78	305.0	.635	.0	1.95	.759	1394.46	460.25	-10.00
5.0	7.78	393.0	.152	.0	1.95	.759	609.90	367.89	-10.00
6.0	7.78	135.0	.046	.0	3.89	1.013	302.06	277.37	-10.00
7.0	7.78	135.0	.152	.0	3.89	1.013	393.50	256.03	-10.00
8.0	7.78	135.0	.318	.0	3.89	1.013	883.62	542.54	-10.00
9.0	7.78	300.0	.318	.0	3.89	1.013	879.65	583.69	-10.00
10.0	7.78	300.0	.318	.0	3.89	1.013	1466.09	1164.34	-10.00
11.0	7.78	300.0	.635	.0	3.89	1.013	1466.09	687.32	-10.00
12.0	7.78	300.0	.318	.0	7.78	1.267	909.52	690.37	-10.00
13.0	7.78	300.0	.318	.0	15.56	1.491	916.53	754.38	-10.00
14.0	7.78	300.0	.318	.0	15.56	1.491	1425.55	1179.58	-10.00
15.0	7.78	300.0	.635	.0	15.56	1.491	1432.56	1037.84	-10.00
16.0	7.78	305.0	.635	.0	15.56	1.491	1556.00	1109.47	-10.00
17.0	7.78	332.0	1.270	.0	15.56	1.491	1660.55	759.56	-10.00

END

SAMPLE OUTPUT FOR 7/F [illegible] PREDICTION PLATE THICKNESS

TITLE THE ALLOY

NO	TEMP	TMOD	ANG	MASS	RHOA	VS	VR	RMASS	MOIA	THICK	X1	DEV	SUM	SU	R.E.	SUM	SO
1.0	4.45	190.0	0.0	1.95	0.759	567.5	521.2	1.48	0.00	0.127	0.047	-0.080	-0.080	0.006	-0.630	-0.630	0.397
2.0	4.45	190.0	0.0	1.95	0.759	1461.8	1294.2	6.91	0.00	0.127	0.154	0.027	-0.053	0.007	0.211	-0.419	0.442
3.0	4.45	190.0	0.0	1.95	0.759	830.3	590.4	-10.00	0.00	0.318	0.304	-0.014	-0.067	0.007	-0.044	-0.462	0.444
4.0	4.45	190.0	0.0	1.95	0.759	1355.4	1085.6	1.63	0.00	0.318	0.262	-0.056	-0.123	0.010	-0.175	-0.638	0.474
5.0	4.45	190.0	0.0	1.95	0.759	1491.1	563.4	1.73	0.00	0.635	0.801	0.166	0.043	0.038	0.262	-0.376	0.543
6.0	4.45	190.0	0.0	1.95	0.759	1985.4	1127.2	0.56	0.00	0.635	0.744	0.109	0.153	0.050	0.172	-0.204	0.572
7.0	4.45	190.0	0.0	1.95	0.759	2371.7	381.6	-10.00	0.00	1.270	1.773	0.503	0.655	0.303	0.396	0.192	0.729
8.0	4.45	190.0	0.0	3.89	1.013	798.9	672.7	3.83	0.00	0.127	0.149	0.022	0.677	0.303	0.173	0.365	0.759
9.0	4.45	190.0	0.0	3.89	1.013	1032.7	957.7	1.72	0.00	0.127	0.086	-0.041	0.636	0.305	-0.322	0.043	0.863
10.0	4.45	190.0	0.0	3.89	1.013	[illegible]	500.8	3.83	0.00	0.318	0.136	-0.182	0.454	0.338	-0.574	-0.531	1.192
11.0	4.45	190.0	0.0	3.89	1.013	773.3	582.6	3.61	0.00	0.318	0.223	-0.095	0.359	0.347	-0.298	-0.829	1.280
12.0	4.45	190.0	0.0	3.89	1.013	1499.0	1251.8	2.43	0.00	0.318	0.254	-0.064	0.295	0.351	-0.200	-1.029	1.321
13.0	4.45	190.0	0.0	3.89	1.013	1505.7	774.5	3.24	0.00	0.635	0.804	0.169	0.464	0.360	0.266	-0.763	1.391
14.0	4.45	190.0	0.0	3.89	1.013	1520.1	979.3	-10.00	0.00	0.635	0.584	-0.051	0.414	0.382	-0.080	-0.843	1.398
15.0	4.45	190.0	0.0	3.89	1.013	2455.2	1367.3	0.12	0.00	0.635	0.940	0.305	0.719	0.475	0.480	-0.363	1.626
16.0	4.45	190.0	0.0	3.89	1.013	2551.8	1165.9	0.57	0.00	1.270	1.223	-0.047	0.672	0.477	-0.037	-0.399	1.630
17.0	4.45	190.0	0.0	7.78	1.267	641.0	501.4	7.72	0.00	0.127	0.117	-0.010	0.662	0.477	-0.076	-0.475	1.536
18.0	4.45	190.0	0.0	7.78	1.267	959.2	874.6	7.72	0.00	0.127	[illegible]	-0.001	0.661	0.477	-0.009	-0.484	1.636
19.0	4.45	190.0	0.0	7.78	1.267	976.0	785.5	7.72	0.00	0.318	0.285	-0.033	0.628	0.479	-0.103	-0.588	1.646
20.0	4.45	190.0	0.0	7.78	1.267	1484.4	994.9	-10.00	0.00	0.635	0.672	0.037	0.665	0.480	0.058	-0.530	1.650

MEAN, VARIANCE AND STANDARD DEVIATION OF DEVIANTS = 0.03324 0.02409 0.15522

MEAN, VARIANCE AND STANDARD DEVIATION OF RELATIVE ERROR -0.02651 0.08608 0.29340

NUMBER OF POINTS = 20

SAMPLE OUTPUT FOR 7/F FITTING PREDICTING PLATE THICKNESS

PHA

NO	THEO	TEMP	ANG	MASS	PHIA	VS	VR	DMASS	MUIA	THICK	XI	DEV	SUM	SQ	R.E.	SUM	SQ
1.0	7.78	135.0	0.0	1.95	0.759	588.5	845.9	-10.00	0.00	0.046	0.033	-0.013	-0.013	0.000	-0.284	-0.284	0.081
2.0	7.78	135.0	0.0	1.95	0.759	1211.6	1015.0	-10.00	0.00	0.152	0.144	-0.008	-0.021	0.000	-0.055	-0.339	0.084
3.0	7.78	300.0	0.0	1.95	0.759	1521.3	1195.3	-10.00	0.00	0.318	0.177	-0.141	-0.162	0.020	-0.443	-0.781	0.279
4.0	7.78	305.0	0.0	1.95	0.759	1394.5	460.3	-10.00	0.00	0.635	0.561	-0.074	-0.237	0.026	-0.117	-0.898	0.293
5.0	7.78	393.0	0.0	1.95	0.759	609.9	367.9	-10.00	0.00	0.152	0.119	-0.033	-0.269	0.027	-0.218	-1.115	0.340
6.0	7.78	135.0	0.0	3.89	1.013	362.1	277.4	-10.00	0.00	0.046	0.024	-0.022	-0.292	0.027	-0.488	-1.603	0.578
7.0	7.78	135.0	0.0	3.89	1.013	393.5	255.0	-10.00	0.00	0.152	0.136	-0.016	-0.308	0.027	-0.107	-1.710	0.590
8.0	7.78	135.0	0.0	3.89	1.013	883.6	542.5	-10.00	0.00	0.318	0.341	0.023	-0.285	0.028	0.072	-1.638	0.595
9.0	7.78	300.0	0.0	3.89	1.013	679.6	583.7	-10.00	0.00	0.318	0.210	-0.108	-0.393	0.040	-0.339	-1.977	0.710
10.0	7.78	300.0	0.0	3.89	1.013	1466.1	1164.3	-10.00	0.00	0.318	0.187	-0.131	-0.524	0.057	-0.411	-2.388	0.879
11.0	7.78	300.0	0.0	3.89	1.013	1466.1	687.3	-10.00	0.00	0.635	0.518	-0.117	-0.641	0.071	-0.185	-2.573	0.914
12.0	7.78	300.0	0.0	7.78	1.267	909.5	690.4	-10.00	0.00	0.318	0.199	-0.119	-0.760	0.085	-0.375	-2.948	1.054
13.0	7.78	300.0	0.0	15.56	1.491	916.5	754.4	-10.00	0.00	0.318	0.212	-0.106	-0.867	0.096	-0.334	-3.282	1.168
14.0	7.78	300.0	0.0	15.55	1.491	1425.6	1179.6	-10.00	0.00	0.318	0.283	-0.035	-0.902	0.097	-0.110	-3.392	1.178
15.0	7.78	300.0	0.0	15.56	1.491	1432.6	1037.8	-10.00	0.00	0.635	0.464	-0.171	-1.072	0.126	-0.269	-3.661	1.250
16.0	7.78	305.0	0.0	15.56	1.491	1556.0	1109.5	-10.00	0.00	0.635	0.506	-0.129	-1.201	0.143	-0.203	-3.864	1.291
17.0	7.78	332.0	0.0	15.56	1.491	1660.5	759.6	-10.00	0.00	1.270	1.029	-0.241	-1.442	0.201	-0.189	-4.053	1.327

MEAN, VARIANCE AND STANDARD DEVIATION OF DEVIANTS = -0.05481 0.00491 0.07006

MEAN, VARIANCE AND STANDARD DEVIATION OF RELATIVE ERROR -0.23842 0.02253 0.15010

NUMBER OF POINTS = 17

END OF RUN

```
C
C
C
COMM      PROGRAM USING THE THOR EQUATION TO PREDICT PLATE THICKNESS
C
C         GLOSSARY OF VARIABLES
C
C
C   ***        IDENTIFIES REQUIRED INPUT DATA
C     *        IDENTIFIES INPUT DATA WHICH IS NOT REQUIRED
C
C
C   ***   ANG     - THE ANGLE OF THE TARGET PLATE WITH RESPECT TO
C                     LINE OF FLIGHT  - OBLIQUITY  (DEGREES)
C         AREA    - THE PROJECTED CROSS-SECTIONAL AREA OF PROJECTILE
C                     ON IMPACT
C         D       - THE DEVIANT =  COMPUTED VALUE MINUS EXPERIMENTAL VALUE
C         DBAR    - THE AVERAGE (MEAN) VALUE OF THE DEVIANTS
C         DSD     - THE STANDARD DEVIATION OF THE DEVIANTS
C         DTOR    - CONVERSION FACTOR -  DEGREES TO RADIANS
C         DVAR    - THE VARIANCE OF THE DEVIANTS
C         F1      - CONSTANT BASED ON LEAST SQUARE FIT TO DATA
C         F2      - CONSTANT BASED ON LEAST SQUARE FIT TO DATA
C         F3      - CONSTANT BASED ON LEAST SQUARE FIT TO DATA
C         F4      - CONSTANT BASED ON LEAST SQUARE FIT TO DATA
C         F5      - CONSTANT BASED ON LEAST SQUARE FIT TO DATA
C         EBAR    - THE AVERAGE (MEAN) VALUE OF THE RELATIVE ERROR
C         ESD     - THE STANDARD DEVIATION OF THE RELATIVE ERROR
C         EVAR    - THE VARIANCE OF THE RELATIVE ERROR
C     *   HDIA    - THE DIAMETER OF THE HOLE MADE IN THE TARGET  (CM)
C         ICT     - INDEX TO COUNT NUMBER OF DATA CARDS FOR ONE TARGET
C     *   IDN     - AN IDENTIFICATION NUMBER OR SYMBOL-DESIGNATES SHOT NR.
C   ***   PDIA    - DIAMETER OF THE PROJECTILE (CM)
C   ***   PMASS   - MASS OF PROJECTILE  (GRAMS)
C         RELERR  - THE RELATIVE ERROR OF COMPUTED VS. EXPERIMENTAL
C     *   RMASS   - THE RECOVERED PROJECTILE MASS  (GRAMS)
C         SUMD    - THE SUM OF THE DEVIANTS
C         SUMDSQ  - THE SUM OF THE DEVIANT SQUARED
C         SUMRE   - THE SUM OF THE RELATIVE ERROR
C         SUMRES  - THE SUM OF THE RELATIVE ERROR SQUARED
C     *   TBHN    - THE TARGET BRINELL HARDNESS NUMBER  (KG/SQ MM)
C     *   THICK   - THE THICKNESS OF THE TARGET PLATE  (CM)
C     *   TRHO    - THE DENSITY OF THE TARGET PLATE  (G/CC)
C   ***   VRE     - THE EXPERIMENTAL RESIDUAL VELOCITY  (M/S)
C   ***   VSP     - THE EXPERIMENTAL STRIKING VELOCITY  (M/S)
C         XT      - THE PREDICTED TARGET PLATE THICKNESS  (CM)
C
```

```
      DATA PI,DTOR / 3.141592654, 0.0174532925 /
   10 FORMAT( A6,2F6.1,F8.3,F5.1,2F6.3,2F8.1,2F7.2)
   11 FORMAT(5F10.3)
   12 FORMAT(10A6)
   20 FORMAT(1H0,10X,13HEXPONENTS ARE , 5F10.3  / )
  100 CONTINUE
      WRITE(6,103)
  103 FORMAT(1H1)
      WRITE(6,106)
  106 FORMAT(1H0,20X,42HSAMPLE OUTPUT FOR THOR EQUATION PREDICTING ,
     1  16H PLATE THICKNESS  / )
C           READ CARD WHICH IDENTIFIES TARGET MATERIAL
      READ(5,12)TGT1,TGT2,TGT3
      WRITE(6,12)TGT1,TGT2,TGT3
      READ(5,11)E1,E2,E3,E4,E5
      WRITE(6,20)E1,E2,E3,E4,E5
      WRITE(6,110)
  110 FORMAT(1H0,4X,31HNR  TRHO  TBHN  ANG  MASS  PDIA , 6X,2HVS,6X,
     1     24HVR  RMASS  HDIA  THICK , 6X,2HXT,5X,3HDEV,5X,
     2     3HSUM,6X,2HSQ,4X,4HR.E.,5X,3HSUM,6X,2HSQ )
      SUMD=0.0
      SUMDSQ=0.0
      SUMRE=0.0
      SUMRES=0.0
      ICT=0
C          ONE BLANK CARD USED TO SEPARATE DATA FOR DIFFERENT TARGETS
C          A CARD WITH  END  PUNCHED IN THE FIRST THREE COLUMNS
C          WILL TERMINATE THE PROGRAM
  150 READ(5,10)IDN,TRHO,TBHN,THICK,ANG,PMASS,PDIA,VSP,VRE,RMASS,HDIA
      IF(TRHO.LE.0.0)GOTO 200
C          COMPUTE PROJECTILE CROSS-SECTIONAL AREA
      AREA=PI*(PDIA/2.0)**2
C          THE UNIT OF VELOCITY TO BE USED IS CM/SEC
      VS=VSP*100.0
      VR=VRE*100.0
      Q1=10.0**E1
      Q3=PMASS**E3
      Q4=(1.0/COS(ANG*DTOR))**E4
      Q5=VS**E5
C          COMPUTE THE PREDICTED TARGET PLATE THICKNESS
      XT=((VS-VR)/(Q1*Q3*Q4*Q5))**(1.0/E2)/AREA
C          COMPUTE DEVIANT  AND RELATIVE ERROR AND CORRESPONDING SUMMATION
      D=XT-THICK
      SUMD=SUMD+D
      SUMDSQ=SUMDSQ+D**2
      RELERR=D/THICK
      SUMRE=SUMRE+RELERR
```

```
      SUMRES=SUMRES+RELERR**2
      WRITE(6,155)IDN,TRHO,TBHN,ANG,PMASS,PDIA,VSP,VRE,RMASS,HDIA,
     1     THICK,XT,D,SUMD,SUMDSQ,RELERR,SUMRE,SUMRES
      ICT=ICT+1
      GOTO 150
  155 FORMAT(1H ,A6,F6.2,F6.1,F5.1,F6.2,F6.3,2F8.1,2F7.2,8F8.3)
  200 CT=ICT
      CT1=ICT-1
C         FIND THE MEAN,VARIANCE AND STANDARD DEVIATION OF
C         DEVIANTS AND RELATIVE ERROR
      DBAR=SUMD/CT
      DVAR=(SUMDSQ-DBAR**2*CT)/CT1
      DSD=SQRT(DVAR)
      EBAR=SUMRE/CT
      EVAR=(SUMRES-EBAR**2*CT)/CT1
      ESD=SQRT(EVAR)
      WRITE(6,210)DBAR,DVAR,DSD
      WRITE(6,215)EBAR,EVAR,ESD
  210 FORMAT(1H0,10X,37HMEAN, VARIANCE AND STANDARD DEVIATION ,2X,
     1    14HOF DEVIANTS =   , 3F10.5 )
  215 FORMAT(1H0,10X,37HMEAN, VARIANCE AND STANDARD DEVIATION ,2X,
     1    17HOF RELATIVE ERROR , 3F10.5)
C         PRINT NUMBER OF POINTS
      WRITE(6,220)ICT
  220 FORMAT(1H0,10X,18HNUMBER OF POINTS = , I5)
      IF(IDN.EQ. 6HEND    )GOTO 900
      GOTO 100
  900 WRITE(6,905)
  905 FORMAT(1H0,30X,10HEND OF RUN )
      STOP
      END
*     DATA
TITANIUM ALLOY
   4.848      1.103     -1.095      1.369      0.167
   1.0   4.48 190.0     .127    .0   1.95   .759  567.84   521.21    1.88
   2.0   4.48 190.0     .127    .0   1.95   .759 1461.82  1294.18     .91
   3.0   4.48 190.0     .318    .0   1.95   .759  880.26   590.40  -10.00
   4.0   4.48 190.0     .318    .0   1.95   .759 1355.45  1083.56    1.63
   5.0   4.48 190.0     .635    .0   1.95   .759 1491.08   683.36    1.73
   6.0   4.48 190.0     .635    .0   1.95   .759 1986.38  1127.15     .56
   7.0   4.48 190.0    1.270    .0   1.95   .759 2371.65   381.61  -10.00
   8.0   4.48 190.0     .127    .0   3.89  1.013  798.88   672.69    3.83
   9.0   4.48 190.0     .127    .0   3.89  1.013 1032.66   957.68    1.72
  10.0   4.48 190.0     .318    .0   3.89  1.013  620.27   500.79    3.83
  11.0   4.48 190.0     .318    .0   3.89  1.013  773.28   582.78    3.51
  12.0   4.48 190.0     .318    .0   3.89  1.013 1499.01  1251.81    2.43
  13.0   4.48 190.0     .635    .0   3.89  1.013 1505.71   774.50    3.24
```

14.0	4.48	190.0	.635	.0	3.89	1.013	1526.13	979.32	-10.00
15.0	4.48	190.0	.635	.0	3.89	1.013	2455.16	1367.33	.12
16.0	4.48	190.0	1.270	.0	3.89	1.013	2551.79	1165.86	.57
17.0	4.48	190.0	.127	.0	7.78	1.267	640.99	561.44	7.72
18.0	4.48	190.0	.127	.0	7.78	1.267	959.21	874.78	7.72
19.0	4.48	190.0	.318	.0	7.78	1.267	975.97	785.47	7.72
20.0	4.48	190.0	.635	.0	7.78	1.267	1484.38	994.87	-10.00

RHA

5.690	0.889	-0.945	0.989	0.019					
1.0	7.78	135.0	.046	.0	1.95	.759	888.49	848.87	-10.00
2.0	7.78	135.0	.152	.0	1.95	.759	1211.58	1014.98	-10.00
3.0	7.78	300.0	.318	.0	1.95	.759	1521.26	1196.34	-10.00
4.0	7.78	305.0	.635	.0	1.95	.759	1394.46	460.25	-10.00
5.0	7.78	393.0	.152	.0	1.95	.759	609.90	367.89	-10.00
6.0	7.78	135.0	.046	.0	3.89	1.013	302.06	277.37	-10.00
7.0	7.78	135.0	.152	.0	3.89	1.013	393.50	256.03	-10.00
8.0	7.78	135.0	.318	.0	3.89	1.013	883.62	542.54	-10.00
9.0	7.78	300.0	.318	.0	3.89	1.013	879.65	583.69	-10.00
10.0	7.78	300.0	.318	.0	3.89	1.013	1466.09	1164.34	-10.00
11.0	7.78	300.0	.635	.0	3.89	1.013	1466.09	687.32	-10.00
12.0	7.78	300.0	.318	.0	7.78	1.267	909.52	690.37	-10.00
13.0	7.78	300.0	.318	.0	15.56	1.491	916.53	754.38	-10.00
14.0	7.78	300.0	.318	.0	15.56	1.491	1425.55	1179.58	-10.00
15.0	7.78	300.0	.635	.0	15.56	1.491	1432.56	1037.84	-10.00
16.0	7.78	305.0	.635	.0	15.56	1.491	1556.00	1109.47	-10.00
17.0	7.78	332.0	1.270	.0	15.56	1.491	1660.55	759.56	-10.00

END

[illegible] PLATE THICKNESS

TITA[illegible]

[illegible] 4.[illegible] 1.1[illegible]3 -1.[illegible] 1.3[illegible] 0.167

[illegible]	[illegible]	[illegible]	[illegible]	MASS	[illegible]	VS	V[illegible]	[illegible]ASS	[illegible]	THICK	XI	DEV	SUM	SQ	R.E.	SUM	SQ
1.0	[illegible]	[illegible]	[illegible]	1.95	[illegible].759	567.8	521.[illegible]	1.88	0.00	0.127	0.064	-0.063	-0.063	0.004	-0.495	-0.495	0.245
2.0	[illegible]	[illegible]	[illegible]	1.95	[illegible].759	1461.[illegible]	129[illegible].2	0.91	0.00	0.127	0.177	0.050	-0.013	0.006	0.396	-0.099	0.402
3.0	4.4[illegible]	[illegible]	[illegible]	1.95	[illegible].759	880.3	[illegible].4	-10.00	0.00	0.318	0.315	-0.003	-0.016	0.006	-0.011	-0.110	0.402
4.0	4.4[illegible]	[illegible]	[illegible]	1.95	[illegible].759	1355.4	10[illegible]3.[illegible]	1.53	0.00	0.318	0.276	-0.040	-0.056	0.008	-0.126	-0.236	0.418
5.0	4.4[illegible]	[illegible]	[illegible]	1.95	[illegible].759	1891.1	[illegible]3.4	1.73	0.00	0.635	0.735	0.100	0.044	0.018	0.158	-0.077	0.443
6.0	[illegible].4[illegible]	[illegible]	[illegible]	1.95	[illegible].759	1986.4	1127.2	0.56	0.00	0.635	0.745	0.110	0.154	0.030	0.173	0.095	0.473
7.0	[illegible]	[illegible]	[illegible]	1.95	[illegible].759	2371.7	381.5	-10.00	0.00	1.270	1.553	0.283	0.437	0.110	0.222	0.318	0.522
8.0	4.4[illegible]	[illegible]	[illegible]	3.89	1.013	798.9	672.7	3.63	0.00	0.127	0.167	0.040	0.477	0.112	0.318	0.636	0.623
9.0	4.4[illegible]	[illegible]	[illegible]	3.89	1.013	1032.7	957.7	1.72	0.00	0.127	0.100	-0.027	0.450	0.112	-0.209	0.426	0.667
10.0	4.4[illegible]	[illegible]	[illegible]	3.89	1.013	529.3	50[illegible]	3.63	0.00	0.318	0.165	-0.153	0.298	0.136	-0.480	-0.053	0.897
11.0	[illegible]	[illegible]	[illegible]	3.89	1.013	773.3	[illegible]2.0	3.61	0.00	0.318	0.244	-0.074	0.224	0.141	-0.232	-0.285	0.951
12.0	4.[illegible]	[illegible]	[illegible]	3.89	1.013	1499.0	1251.[illegible]	2.43	0.00	0.318	0.280	-0.038	0.186	0.148	-0.120	-0.405	0.965
13.0	4.4[illegible]	[illegible]	[illegible]	3.89	1.013	1565.7	774.5	3.24	0.00	0.635	0.748	0.113	0.299	0.155	0.177	-0.228	0.997
14.0	4.4[illegible]	[illegible]	[illegible]	3.89	1.013	1525.1	973.3	-10.00	0.00	0.635	0.573	-0.062	0.237	0.159	-0.097	-0.325	1.006
15.0	4.4[illegible]	[illegible]	[illegible]	3.89	1.013	2455.2	1367.3	0.12	0.00	0.635	0.995	0.360	0.597	0.289	0.567	0.243	1.328
16.0	4.4[illegible]	[illegible]	[illegible]	3.89	1.013	2551.8	1165.9	0.57	0.00	1.270	1.232	-0.038	0.560	0.290	-0.030	0.213	1.329
17.0	4.4[illegible]	[illegible]	[illegible]	7.78	1.267	[illegible]41.0	[illegible]1.4	7.72	0.00	0.127	0.145	0.018	0.578	0.291	0.141	0.354	1.349
18.0	4.4[illegible]	[illegible]	[illegible]	7.78	1.267	[illegible]59.2	874.[illegible]	7.72	0.00	0.127	0.144	0.017	0.595	0.291	0.133	0.486	1.366
19.0	4.4[illegible]	[illegible]	[illegible]	7.78	1.267	[illegible]76.0	785.5	7.72	0.00	0.318	0.300	-0.018	0.577	0.291	-0.057	0.430	1.369
20.0	[illegible].4[illegible]	[illegible]	[illegible]	7.78	1.267	1484.4	904.9	-10.00	0.00	0.635	0.662	0.027	0.604	0.292	0.043	0.473	1.371

MEAN, VARIANCE AND STANDARD DEVIATION OF DEVIANTS = 0.03020 0.01441 0.12002

MEAN, VARIANCE AND STANDARD DEVIATION OF RELATIVE ERROR 0.02364 0.07159 0.26755

NUMBER OF POINTS = 20

[illegible] PLATE [illegible]

RHA

[illegible]

NO	TEMP	TIME	[illegible]	MASS	[illegible]	VS	VP	WMASS	[illegible]	THICK	XI	DEV	SUM	SJ	R.E.	SUM	SQ
1.0	7.75	135.0	0.0	1.95	0.759	888.5	840.4	-10.00	0.00	0.635	0.010	-0.030	-0.030	0.001	-0.650	-0.660	0.430
2.0	7.75	135.0	0.0	1.95	0.759	1211.6	1015.3	-10.00	0.00	0.152	0.094	-0.058	-0.088	0.004	-0.381	-1.042	0.552
3.0	7.75	300.0	0.0	1.95	0.759	1521.3	1196.3	-10.00	0.00	0.318	0.165	-0.153	-0.242	0.028	-0.482	-1.524	0.814
4.0	7.75	305.0	0.0	1.95	0.759	1394.5	460.3	-10.00	0.00	0.635	0.541	-0.094	-0.335	0.037	-0.148	-1.672	0.436
5.0	7.75	393.0	0.0	1.95	0.759	509.9	357.9	-10.00	0.00	0.152	0.121	-0.031	-0.367	0.038	-0.207	-1.878	0.879
6.0	7.75	135.0	0.0	3.89	1.013	302.1	277.4	-10.00	0.00	0.046	0.011	-0.035	-0.402	0.039	-0.761	-2.640	1.458
7.0	7.75	135.0	0.0	3.89	1.013	393.5	250.0	-10.00	0.00	0.152	0.075	-0.077	-0.479	0.045	-0.504	-3.144	1.712
8.0	7.75	135.0	0.0	3.89	1.013	883.6	542.5	-10.00	0.00	0.318	0.206	-0.112	-0.591	0.057	-0.353	-3.497	1.837
9.0	7.75	300.0	0.0	3.89	1.013	879.6	583.7	-10.00	0.00	0.318	0.175	-0.143	-0.733	0.078	-0.448	-3.945	2.038
10.0	7.75	300.0	0.0	3.89	1.013	1465.1	1164.3	-10.00	0.00	0.318	0.177	-0.141	-0.874	0.097	-0.442	-4.387	2.233
11.0	7.75	300.0	0.0	3.89	1.013	1655.1	657.3	-10.00	0.00	0.635	0.515	-0.120	-0.994	0.112	-0.188	-4.576	2.269
12.0	7.75	300.0	0.0	7.75	1.267	409.5	690.4	-10.00	0.00	0.318	0.167	-0.151	-1.145	0.134	-0.475	-5.050	2.494
13.0	7.75	300.0	0.0	15.56	1.491	416.5	754.4	-10.00	0.00	0.318	0.180	-0.138	-1.283	0.154	-0.435	-5.486	2.684
14.0	7.75	300.0	0.0	15.56	1.491	1425.6	1179.6	-10.00	0.00	0.318	0.284	-0.034	-1.317	0.155	-0.106	-5.592	2.695
15.0	7.75	300.0	0.0	15.56	1.491	1432.6	1037.8	-10.00	0.00	0.635	0.484	-0.151	-1.468	0.178	-0.238	-5.831	2.752
16.0	7.75	305.0	0.0	15.56	1.491	1556.0	1109.5	-10.00	0.00	0.635	0.555	-0.080	-1.548	0.184	-0.126	-5.957	2.768
17.0	7.75	332.0	0.0	15.56	1.491	1660.5	759.6	-10.00	0.00	1.270	1.220	-0.050	-1.598	0.187	-0.039	-5.996	2.770

MEAN, VARIANCE AND STANDARD DEVIATION OF DEVIANTS = -0.09402 0.00227 0.04766

MEAN, VARIANCE AND STANDARD DEVIATION OF RELATIVE ERROR -0.35272 0.04091 0.20226

NUMBER OF POINTS = 17

END OF RUN

LIST OF SYMBOLS

A Projectile cross-sectional area at impact (cm^2)

a Acceleration

C Projectile shape factor

c_i Empirical constants ($i = 1$, 2 and 3)

F Resistive force

H_t Brinell hardness of target plate ($dynes/cm^2$

K_1 A coefficient $= C_1 H_t$

K_2 A coefficient $= C_2 \sqrt{\rho_t H_t}$

K_3 A coefficient $= C_3 \rho_t$

m Mass

m_p Projectile mass (grams)

q A discriminant $- 4 K_1 K_3 - K_2^2$

T_x Time to penetrate to depth x (sec)

t Time

V Velocity

V_r Residual velocity (cm/sec)

V_s Striking velocity (cm/sec)

V_x Velocity at depth x

x Distance into the target measured from impact surface

X_t Target plate thickness (cm)

ρ_t Density of target plate (g/cc)

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